Mines and Minerals Branch Report of Activities 1989, Part A

D.R. MacDonald
and K.A. Mills,
Editors

Report 89-3

Canada-Nova Scotia
Mineral Development Agreement

Nova Scotia
Department of
Mines and Energy

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Mines and Minerals Branch Report of Activities 1989, Part A

D.R. MacDonald
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Editors

Report 89-3

Nova Scotia

Department of Mines and Energy

Jack MacIsaac
Minister

John J. Laffin, D.Eng., FEIC, P.Eng.
Deputy Minister

Halifax, Nova Scotia
1989

Editors: D. R. MacDonald and K. A. Mills

Word Processing: B. L. MacDonald and B. S. Boutilier

Cartography:
J. Campbell
W. Burt
P. Belliveau
G. MacDonald
C. Phillips
P. Fraser
R. MacPherson
W. Kaiser
E. Limpert
J. Webster
J. DeWolfe

Photography:
C. Murphy
R. Morrison

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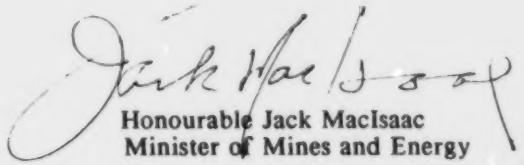
FOREWORD

On behalf of the Nova Scotia Department of Mines and Energy, it is my pleasure to welcome you to the 1989 Open House and Review of Activities. This event provides an excellent opportunity for our staff to present to representatives of the mineral industry and the general public an overview of Departmental activities in the areas of earth science and mineral resources.

This Report provides brief summaries of all major programs and presents preliminary results where possible. These programs, collectively designed to evaluate and promote the development of Nova Scotia's mineral resources, involve staff from both the Mines and Minerals and Energy Branches of the Department, as well as members of the local academic community who are involved in joint research. Most importantly, the Open House provides an opportunity to highlight activities undertaken in the final year of the Canada - Nova Scotia Mineral Development Agreement which has been in place since June of 1984. We welcome, therefore, the participation of Energy, Mines and Resources Canada in our Open House this year.

Nova Scotia has experienced substantial increases in exploration activity in the past few years. Several properties are in the advanced exploration stages. We welcome the addition of gold, copper and zinc to the list of mineral commodities produced in the Province. Equally significant, however, are new developments in the industrial minerals and coal sectors, indications that our traditional mineral industry is alive and well. In this regard, it is important to note that in 1988 the total value of minerals produced exceeded $500 million, a record high.

The Mining Association of Canada, the Prospectors and Developers Association of Canada, the Canadian Institute of Mining and Metallurgy and related organizations like the Chamber of Mineral Resources of Nova Scotia all supported the projects carried out under the Federal-Provincial Mineral Development Agreements. We share these convictions and I am very pleased that we were able to continue some of the programs under the new $9.0 million Mineral Development Agreement that is now being finalized. The presentations made at this Open House bear witness to the collaborative efforts of the Federal and Provincial Departments responsible for mineral development.



Honourable Jack MacIsaac
Minister of Mines and Energy

PETROLEUM ACTIVITIES UPDATE

D. J. MacDonald

INTRODUCTION

As part of its mandate, the Petroleum Resources Section is responsible for all aspects of oil and gas exploration and development in the onshore region of Nova Scotia. In addition to monitoring activity and providing the regulatory regime for petroleum exploration, the Department has been attempting to encourage activity through presentations at international conferences, by maintaining an accessible database to provide entry level information for industry, and by offering lands for exploration bids (Fig. 1).

ONSHORE PETROLEUM RIGHTS AND ACTIVITY

Chevron Canada Resources drilled an exploration well at Mull River in Cape Breton (Fig. 1) last summer which fulfilled the company's obligations under its exploration agreement. The results of the drilling cannot yet be disclosed since the Petroleum Resources Act regulations require information to be held in confidence for a period of two years following the completion of a well. Following various appraisals, Chevron surrendered its holdings in Nova Scotia.

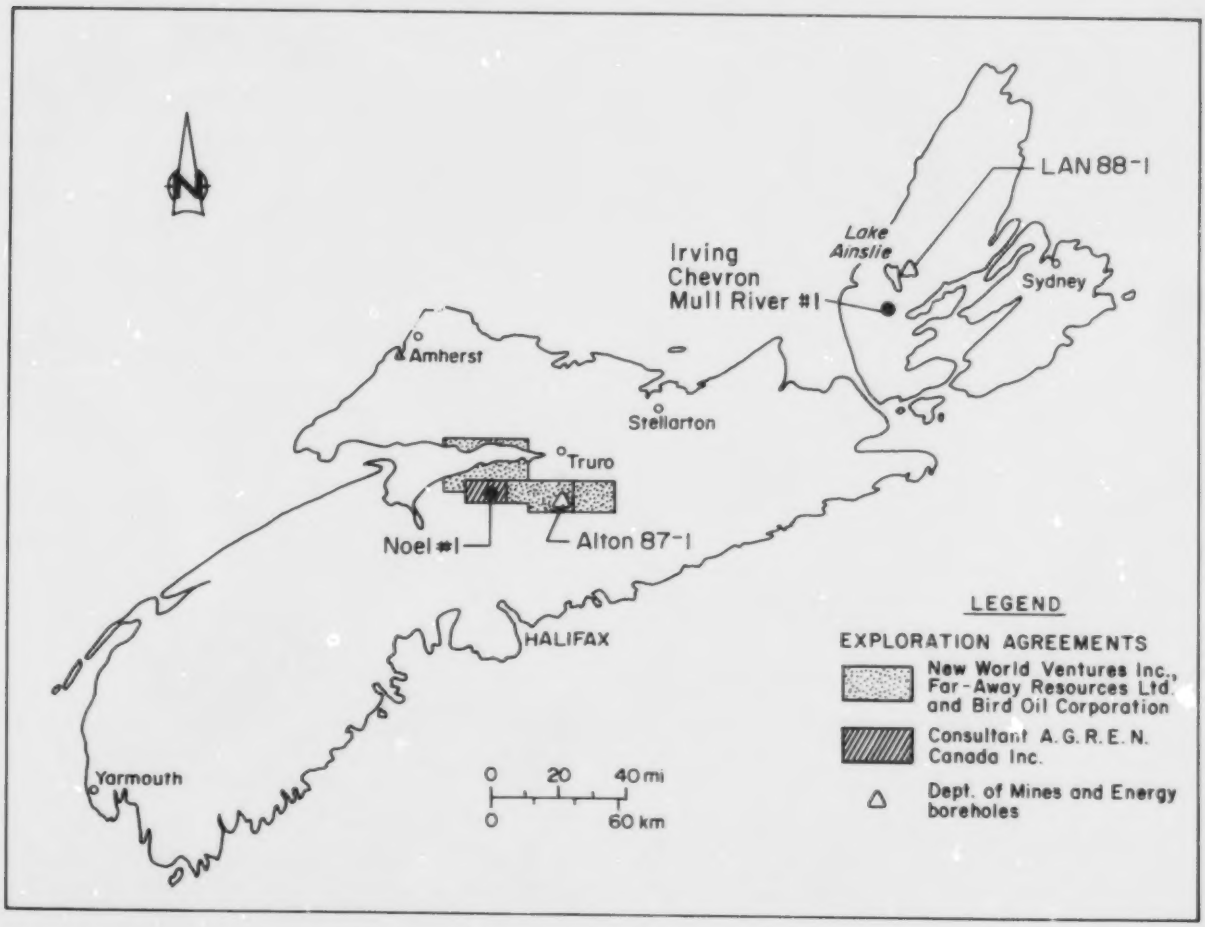


Figure 1. Onshore exploration agreements under administration.

The Noel area of central Nova Scotia is another region of petroleum interest. In 1975 SOQUIP and partners drilled a 1448 m (Noel #1) to evaluate the Horton and Windsor groups section. The well encountered 348 m (1142 ft.) of lower Windsor Group, and 1040 m (3412 ft.) of Horton Group rocks. Shows of gas up to 16% methane were recorded with connection gas as high as 30%. Four drill stem tests were conducted, three in the Horton Group and one in the Windsor Group. All recovered only formation water.

Consultants AGREN currently hold exploration rights to a block of land in the Noel area and are required to drill a well in 1989 prior to the end of the initial term of their exploration agreement. The company carried out a seismic survey in 1986 in the vicinity of the original Noel well and are using the survey to decide the best location for the required well.

A shallow well was drilled by the Department in the fall of 1988 on the east side of Lake Ainslie in Cape Breton. The objective was to collect a sample of oil for the purpose of identifying geochemical characteristics and thus relating the oil to a probable source rock. The well was drilled to a depth of 65.6 m (215 ft.) encountering over 38 m (125 ft.) of porous petroliferous sandstone. The sandstone encountered at depth is very similar to that seen in outcrop. Samples of the sandstone were taken for oil extraction and subsequent analysis. The samples have yielded important information contributing to a better understanding of the likely source of the hydrocarbons.

A 683 m (2240 ft.) diamond-drill hole located at Alton, Colchester County, was undertaken by the Department in 1988 to investigate the Windsor Group evaporite sequence, specifically to determine the extent and thickness of several key horizons. However, the hole had to be terminated in May 1988 due to the uncontrolled flow of natural gas into the borehole. The flow lasted some six days at pressures in excess of 10 342 kPa (1500 psi) before being stopped and the well was subsequently abandoned. Several available open file reports detail the events and provide lithologic descriptions of the core taken.

These events created considerable interest with private sector explorers. Responding to this interest, the Department issued a "Call for Petroleum Exploration Proposals" covering lands in the vicinity. With such calls, persons or companies are invited to submit a proposal of the lands. The bids are then evaluated and where deemed appropriate the lands may be issued under an exploration agreement to the successful bidder. The blocks in question covered an area of 105 077 hectares (259,642 acres). The posting closed on 31 August 1989 with competitive bids having been received. The bids were evaluated using three main criteria: (1) the proposed work program, (2) the financial and technical capability of the applicant, and (3) the availability of a performance bond. All three blocks were subsequently awarded to a consortium of three companies: New World Ventures and Far Away Resources of Calgary and Bird Oil of Denver. The work programs, which form part of the agreements, provide for a well to be drilled on each block within a three year period. Work expenditure proposals for these three blocks total some $1.8 million.

A similar Call for Proposals for offshore lands closed on 31 July 1989 and was also successful. Competitive bids were received on the three blocks offered to the west of Sable Island, resulting in some $19.4 million being bid in work programs for these lands. Under the terms of the resulting exploration agreements, one well is required to be drilled on each block before the end of year three, if rights are to be maintained.

ONSHORE PETROLEUM SOURCE ROCK STUDY

The petroleum source rock study undertaken as an EDA project is in its final stages. Organic geochemistry and maturation profiles were used to classify a variety of potential source rocks throughout the Carboniferous in the onshore region. Preliminary plots suggest that Windsor Group rocks have greater potential as hydrocarbon sources, in most regions, than the oft-touted Horton Group 'grey beds'.

In the Mabou-Lake Ainslie area of western Cape Breton, it is concluded that many of the oil seeps and shows documented are likely derived from Windsor Group carbonates. Much of the oil appears to be located in the older Horton Group sandstone. This was likely accomplished by faulting which provided the opportunity for migration of the hydrocarbons.

The study's final maps display the trends and location of rock units favourable to the production of hydrocarbons. As with many studies there are a number of significant findings and recommendations for additional work. Among

those are, of course, additional work in the Lake Ainslie area, an examination of the potential of upper and post Carboniferous rocks, and those are, of course, additional work in the Lake Ainslie area, an examination of the potential of upper and post Carboniferous rocks, and investigations of reservoir rocks that may have been the benefactors of migration from the source rocks under study. The report and accompanying maps should be available in the early spring.

OFFSHORE ACTIVITY

In related work, the Department has undertaken an investigation to aid in the better understanding of hydrocarbon migration and trapping. In the offshore there is a thick Jurassic carbonate bank complex that has been penetrated by only a few wells. No discoveries have been made in this unit and it has not been the major focus of investigation. Excellent porosity has been recorded and the bank's proximity to rich source rock adds further intrigue. The purpose of the study was to determine if the thick porosity intervals are in fact discernible on seismic data. Assuming that this link could be established, the study focused on the minimum thickness and porosity value necessary for seismic resolution.

Staff were heavily involved in the preparation of a promotional publication for the offshore region. The resulting effort, titled *Petroleum Opportunities Offshore Nova Scotia, Canada*, was produced in conjunction with staff of the Canada Oil and Gas Lands Administration in Ottawa. It is aimed at industry exploration managers and explains the regulatory, fiscal and rights management regimes offshore. It also provides a historical and technical description of the geologic setting and highlights promising exploration targets. The publication has been very well received by industry.

In other promotional efforts, staff attended several technical conferences during the year contributing poster displays and oral presentations on geotechnical topics in both the onshore and offshore.

Besides the successful offshore call for proposals mentioned above, geophysical activity in the offshore has begun once again in the vicinity of the Cohasset-Panuke oil trend. The Development Plan for the Cohasset/Panuke project is expected to be submitted in early 1990. By this time it is also expected that the Canada-Nova Scotia Accord Legislation will have been proclaimed and the new Offshore Petroleum Board will have been established.

PRELIMINARY RESULTS OF DEEP COAL DRILLING AT SOUTH ATHOL, CUMBERLAND BASIN

J. H. Calder and K. S. Gillis

INTRODUCTION

The successful completion of a 1156 m diamond-drill hole at South Athol, Cumberland County (Fig. 1), in March 1989 has significant implications for potential coal resources and for the stratigraphic correlation of coal-bearing strata in the Cumberland Basin. Most importantly, the drillhole verifies the coal-bearing nature of well-defined reflecting events within the Cumberland Group evident in seismic data recently procured by the Geological Survey of Canada under the 1984-89 Canada - Nova Scotia Mineral Development Agreement (Calder and Bromley, 1988; Fig. 1).

LITHOSTRATIGRAPHY

The preliminary lithostratigraphic subdivision of the strata cored in SA-88-1 and -2 is depicted in Figure 2. The uppermost 784 m are dominated by red mudrocks with subordinate grey sandstone and rare extra-basinal conglomerate. At present these strata are assigned to the Ragged Reef Formation (Boehner et al., 1988). There is a rapid lithologic gradation between these red mudrock dominated strata and the cobble conglomerate and predominantly grey strata of the Ragged Reef Formation as exposed on the coast north of Spicers Cove and south of Ragged Reef.

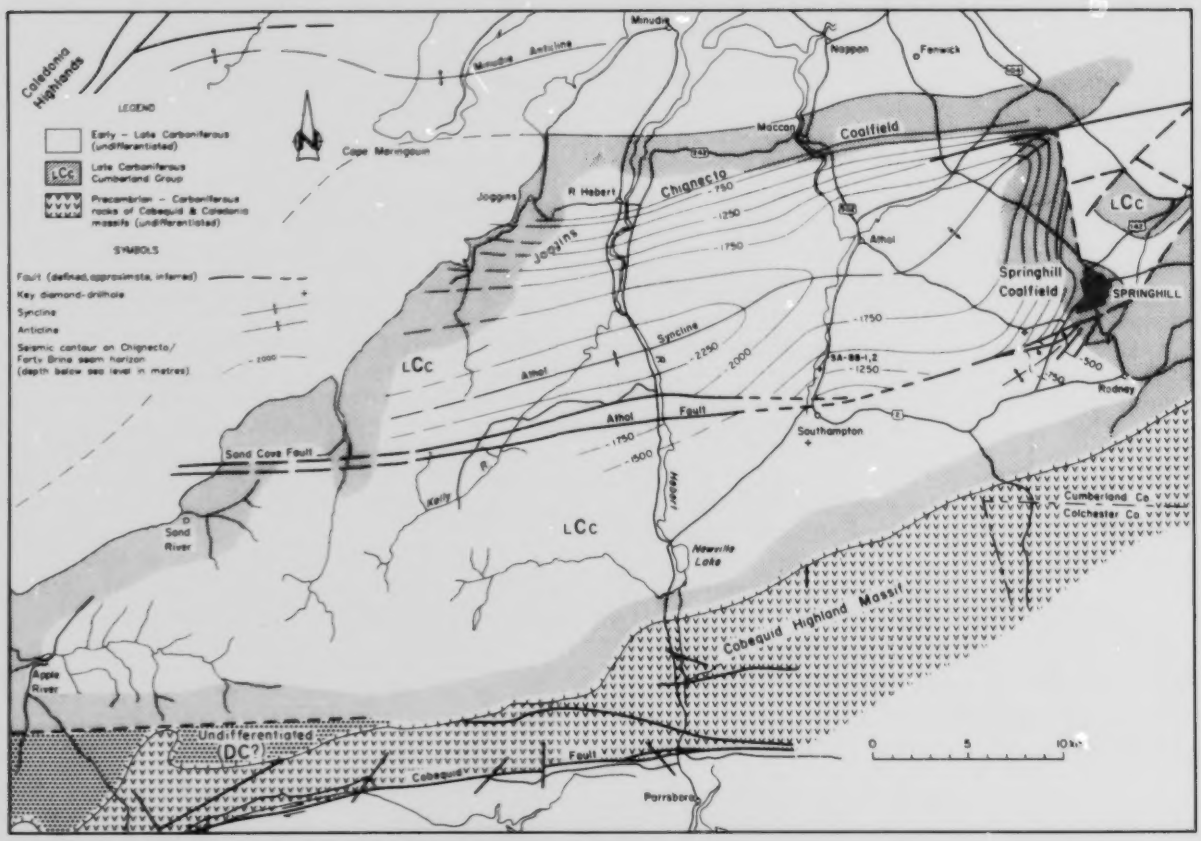


Figure 1. Location of drillholes SA-88-1 and -2, Cumberland Basin.

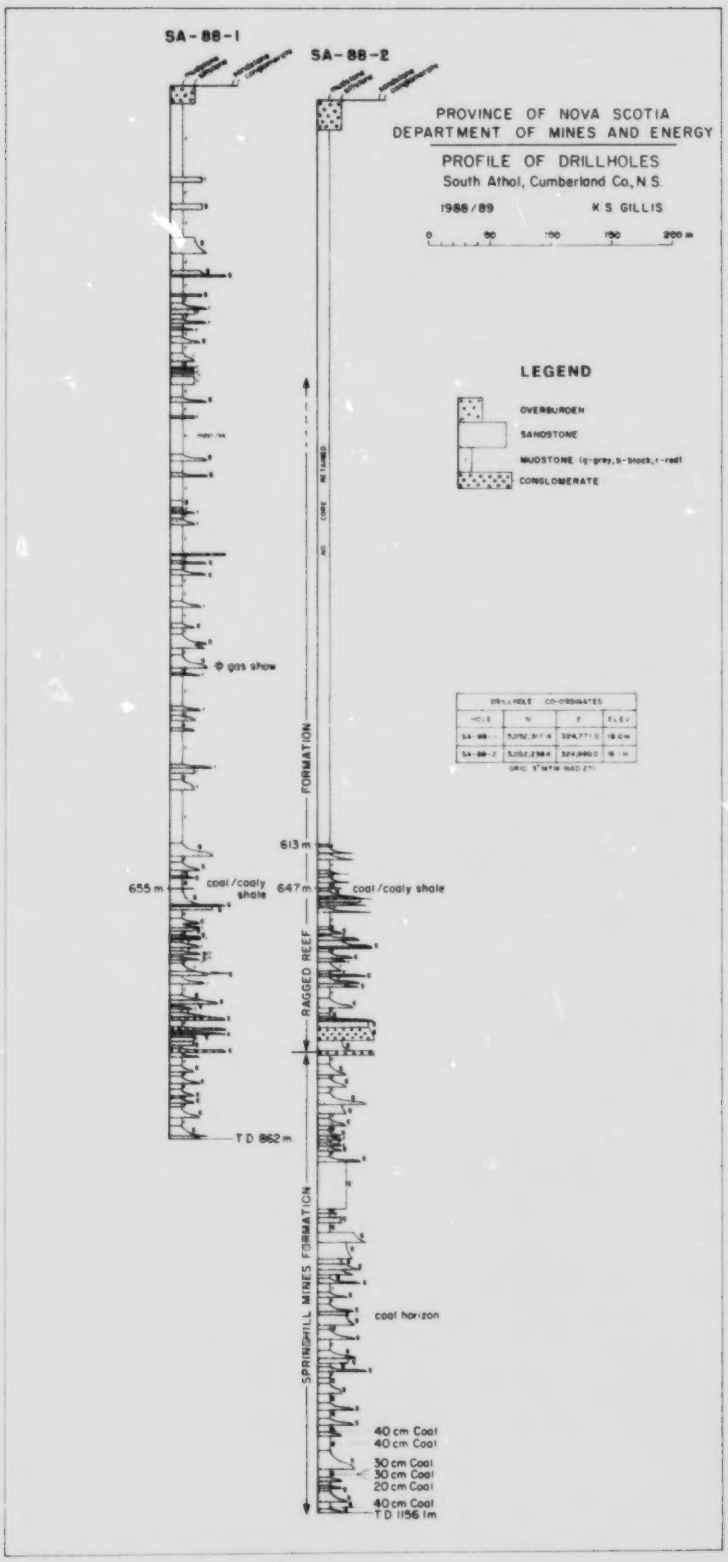


Figure 2. Lithologic profiles of drillholes SA-88-1 and -2, South Athol, Cumberland Basin.

A 210 m thick section of strata characterized by abundant red mudrock and grey multistoried sandstone occurs beneath the unit described above. This assemblage is lithologically similar to strata that occur immediately above the coal-bearing strata of the Springhill Coalfield (Calder, 1986) and to strata of the proposed Springhill Mines Formation exposed between MacCarrons River (McCarrons Creek, historical name) and Ragged Reef on the Joggins shore (Ryan, personal communication). With depth, a lithologic change to grey mudrock, multistoried sandstone and humic coal occurs. The lowermost 160 m of SA-88-2 intersected this coal-bearing unit, which is provisionally correlated with the Springhill Mines Formation. Six seams less than 0.40 m in thickness were intersected before the capacity of drilling was reached at 1156 m.

BIOSTRATIGRAPHY

Samples from the upper 862 m (SA-88-1) submitted for palynological analysis revealed a palynomorph assemblage characteristic of spore zone 5 of Dolby (1988), corresponding in age to the Ragged Reef Formation. Although the lower, coal-bearing strata have not yet been sampled, it is anticipated that these strata will contain a zone 4 assemblage of early mid Westphalian B age, of similar age to the thick seams of the Springhill Coalfield (Dolby, 1988).

COAL RESOURCES

The coals intersected in SA-88-2 are below the minimum seam thickness commonly employed in resource estimation, however extrapolation of the geometric trends of seams at Springhill suggests that the South Athol coals are potentially of a mineable thickness (1.5 m or greater) within an areal distance of 1 km.

Perhaps most significant is the finding that areas of coal-forming peatlands existed over a substantial surface of the Athol Syncline during the Westphalian B, and that coal deposits are not restricted only to the Joggins-Chignecto and Springhill Coalfields.

PETROLEUM OCCURRENCES

A minor flow of natural gas was encountered during intersection of a multistoried sandstone body at a depth of 470 m in drillhole SA-88-1 (Fig. 2).

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PROGRESS REPORT ON A STUDY OF TRACE AND MAJOR ELEMENTS IN NOVA SCOTIA COALS

W. D. Smith

INTRODUCTION

The composition and quantity of the mineral matter (or coal ash) of coal is important because of (1) the requirement to clean coal to reduce the content of ash, sulphur and noxious components prior to burning, (2) the need to reduce the content of noxious components from stack emissions and waste materials, (3) the potential for elements of economic value concentrated in the coal ash (vanadium content in the Hat Creek coals of B. C. is considered to be sufficient to make its recovery from the ash worthwhile: Seyer *in* Bethel, 1962), and (4) potential uses for the residual ash material (such as fly ash in the manufacture of light weight concrete: Carlson, 1989). Additionally, the contents of various elements such as B, Cr, S, Na and K have been used to determine the depositional environment of coal (Nicholls and Loring, 1960; Couch, 1971; Bohor and Gluskoter, 1973; Goodarzi, 1987a,b, 1988; Goodarzi and Cameron, 1987; Goodarzi and van der Flier-Keller, 1988).

CURRENT WORK

Here in Nova Scotia, coal resources are situated on Cape Breton Island and the northern mainland (Fig. 1). Economic coal deposits occur in the Pennsylvanian (Late Carboniferous) Riversdale, Cumberland and Pictou groups, all of continental origin, which were deposited in basins that formed mainly in response to strike-slip movement along the Cobequid-Chedabucto and Hollow fault systems. The coal quality varies from basin to basin, from low sulphur-high ash to high sulphur-low ash with ranks of high volatile bituminous A, high volatile bituminous B or medium- to low-volatile (Calder, 1985).

A survey of literature on Nova Scotia coals has shown that major element analyses have been routinely reported (Table 1), however analyses of trace element contents (usually only a limited number of elements) are less abundant (Table 2). Published and unpublished data are being compiled at the Nova Scotia Department of Mines and Energy. Further work will supplement the existing data with more elemental analyses as well as mineralogical and petrological studies with the following objectives in mind: (1) to identify whether compositional trends exist in the coals (e.g. variation within seam and on a regional, coalfield/basin, level), (2) to determine whether the coals show enrichment in elements (compared to the average abundance of elements within the earth's crust and coals elsewhere), (3) to determine the residency of the elements; whether the elements have an organic (maceral) or inorganic (mineral) affinity, and (4) to determine the depositional environment of the coals and associated strata.

The results of this project work will be of benefit to industry engaged in coal exploration and development. The composition of the coal relates to its quality and impacts on its mineability, therefore the data should prove useful to future exploration and mine planning. Determination of the residency of the elements, deleterious elements especially, should aid in determining measures for their removal or recovery.

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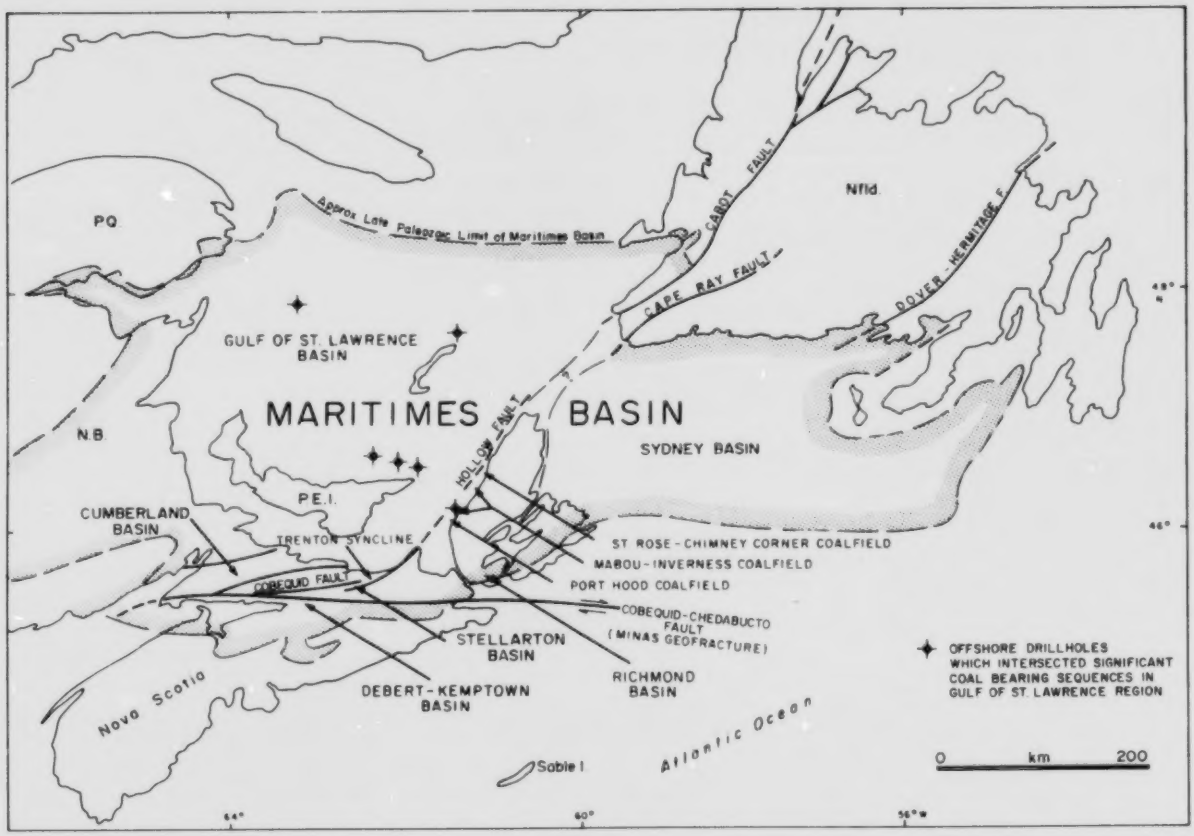

Figure 1. Location map of the coal basins/fields of Nova Scotia showing the Late Paleozoic limit of the Maritimes Basin of Atlantic Canada (modified after Naylor et al., 1989).

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Table 1. Sources of data for major element analyses on Nova Scotia coals: C'LAND = Cumberland Basin; D-K = Debert-Kemptown Basin; STELL = Stellarton Basin; TR S/C - Trenton Syncline; RICH = Richmond Basin; P HOOD = Port Hood Coalfield; M-IN = Mabou-Inverness Coalfield; SR-CC = St. Rose-Chimney Corner Coalfield; SYDNEY = Sydney Basin.

	BASIN/COALFIELD								
SOURCE	C'LAND	D-K	STELL	TR S/C	RICH	P HOOD	M-IN	SR-CC	SYDNEY
Atlantic Coal Institute, 1988	X								
Birk and Zodrow, 1986									X
Bonnell, 1982	X								
Bonnell, 1983			X						X
Bonnell and Janke, 1986			X					X	X
Eastern Coals Database, 1984	X		X						X
Landheer et al., 1982	X		X						X
Montgomery et al., 1970	X		X			X	X	X	X
Strong et al., 1940	X								
Swartzman, 1948	X		X			X	X	X	X
Swartzman, 1953	X		X			X	X	X	X
Swartzman and Tibbetts, 1955	X		X				X	X	X
Tibbetts, 1975			X						
Tibbetts, 1976		X	X						
Tibbetts, 1977			X						
Tibbetts, 1980a			X						
Tibbetts, 1980b	X		X						X
Tibbetts, 1981	X								
Tibbetts and Montgomery, 1960			X						
Zodrow, 1986a									X
Zodrow, 1986b									X
Zodrow, 1987									X

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Table 2. Sources of data for trace element analyses on Nova Scotia coals: abbreviations as in Table 1.

	BASIN/COALFIELD								
SOURCE	C'LAND	D-K	STELL	TR S/C	RICH	P HOOD	M-IN	SR-CC	SYDNEY
Atlantic Coal Institute, 1988	X								
Birk and Zodrow, 1986									X
Bonnell and Janke, 1986			X					X	X
Eastern Coals Database, 1984			X						X
Hawley, 1955a						X		X	X
Hawley, 1955b						X(ppm Ge)		X(ppm Ge)	X(ppm Ge)
Kaplan, 1980	X								
Kaplan et al., 1985	X								
Landheer et al., 1982	X		X						X
Yeo et al., 1988			X	X					
Zodrow, 1986a									X
Zodrow, 1986b									X
Zodrow, 1987									X
Zodrow et al., 1987									X(ppm U)

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SEDIMENTOLOGY OF A LACUSTRINE SEQUENCE CAPPING THE HARBOUR SEAM, SYDNEY COALFIELD

D. J. MacNeil, R. D. Naylor, B. Cox and L. P. Whitman

INTRODUCTION

The Sydney Coalfield contains the largest commercial bituminous coal resource in Canada east of Alberta. Currently, total production for the Sydney Coalfield exceeds 3 million t of raw coal per year with greater than 95% coming from underground mines on the Harbour (Lingan Colliery), Hub (Prince Colliery) and Phalen (Phalen Colliery) seams. Approximately 70% of Nova Scotia's electrical generating capacity depends on this indigenous coal resource.

As mine development and coal marketing become subject to more stringent economic, technical and environmental constraints, the role of the geologist in predicting changes in coal seam quality, geometry, roof and floor conditions has become more critical. In cooperation with the Cape Breton Development Corporation (CBDC) Geology Department, the Nova Scotia Department of Mines and Energy Coal Section has initiated a detailed study of the sedimentology of a limestone-bearing lacustrine sequence which locally overlies the Harbour seam. Observations by CBDC geologists and others (Hacquebard et al., 1965; Cameron, 1971) have indicated that lacustrine roof sequences correlate with areas of reduced seam thickness as well as changes in coal quality.

CURRENT WORK

The purpose of this phase of the study is to determine the controls that lacustrine systems exerted on the deposition and development of the Harbour seam within the Donkin Resource Block, which contains a major untapped coal reserve on this seam. This block has been explored by 11 offshore boreholes (Fig. 1) providing a variety of data including core, downhole geophysics and coal analyses. As well, exploration tunnels have been driven to the seam.

Cored sequences of the Harbour roof strata have been logged and compared with two excellent exposures of lacustrine strata overlying the Harbour Seam at Glace Bay and Bridgeport. Two

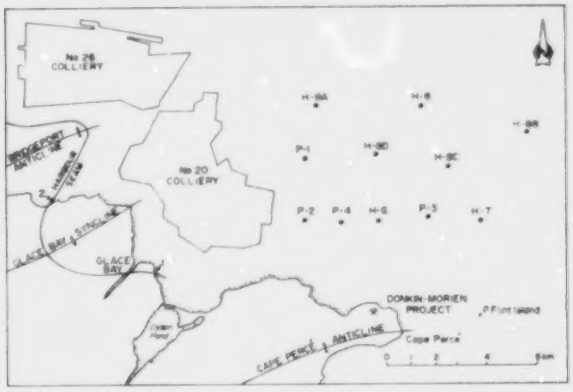

Figure 1. Location map of Glace Bay-Donkin area, Sydney Coalfield.

distinctive lithofacies assemblages are apparent. Assemblage #1 comprises limestone, varved mudrock, and parallel and ripple laminated sandstone, characterized locally by pelecypod remains and burrows, ostracodes and fish remains with thin beds of cannel shale. This assemblage is entirely of lacustrine origin (Fig. 2). Assemblage #2 comprises extensively bioturbated and faintly laminated mudrock and fine grained sandstone characterized by siderite, siderite bands, and sideritic and calcareous concretions. These are interpreted as floodplain and marginal lacustrine deposits which have been subjected to soil-forming processes (Fig. 2).

Previous work by Hacquebard et al. (1965) showed that deposition of Harbour seam peat was locally terminated by development of a lake in the Glace Bay area. Elsewhere in the coalfield, peat deposition continued. The present work indicates that the 'Harbour Lake' is extensive in the Glace Bay-Donkin area. Various lithologies within the lacustrine Assemblage #1, such as cannel shales and pelecypod-bearing varved mudrocks, can be reliably correlated over distances of 3 - 10 km.

FUTURE PLANS

Reconstruction of the depositional history of the

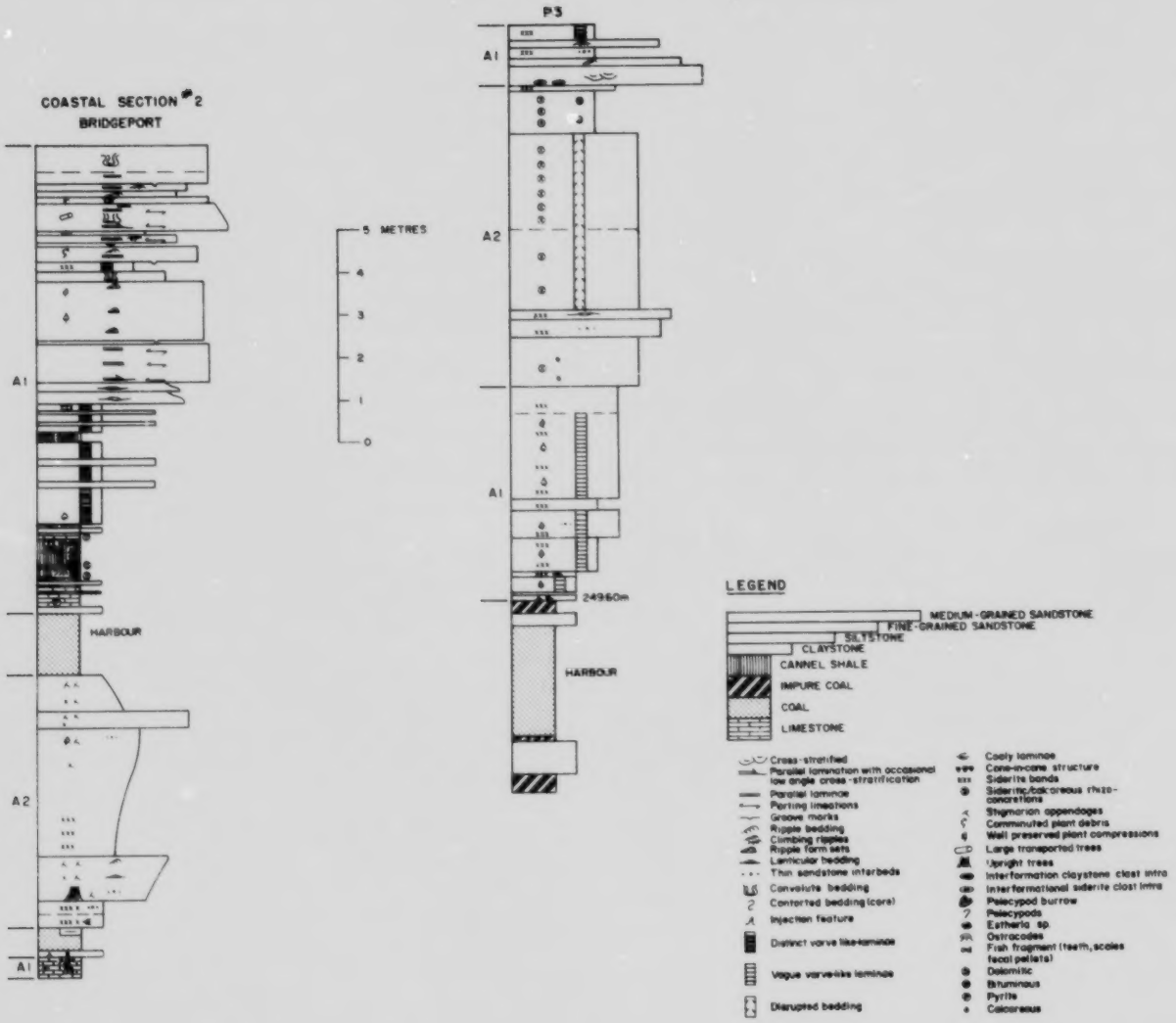

Figure 2. Examples of typical lithofacies assemblages found associated with the Harbour seam. Assemblage 1: limestone-vared mudrock/parallel and ripple laminated sandstone. Assemblage 2: bioturbated sandstone and mudrock with rhizoconcretions and diagenetic alteration by soil-forming processes.

Harbour seam and roof strata in this area can help develop predictive tools for determining changes in roof conditions, seam thickness and coal quality in underground mining. Ongoing work includes completion of detailed logging of roof sequences to produce a detailed roof stratigraphy. Trace element analyses of coal and roof strata are being integrated with studies of sedimentology. Further study of the organic petrography of the Harbour seam to supplement work by Hacquebard et al. (1965) and Cameron (1971) is also planned.

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DATABASE DEVELOPMENT AND COMPUTER MODELLING OF NOVA SCOTIA COALFIELDS[1]

J. D. Hughes[2], P. Watson[3] and D. J. MacNeil

Work continued in 1988-89 on development of a computer database of geological and coal quality data for Nova Scotia, under the Canada-Nova Scotia Mineral Development Agreement. Information from borehole logs, outcrop descriptions, channel samples collected from underground workings, and digitized topographic and bathymetric maps of coalfields are included in the database. The reader is referred to Hughes et al. (1986) for an account of the procedures used in acquisition, interpretation and verification of the various data.

During 1988-89, data entry continued for the Pictou Coalfield. As well, entry of locational, lithologic and analytical information was completed for more than 4000 channel samples from the underground mines, in the Sydney Coalfield. These channel samples include some 21,000 ply analyses. Verification of the computer data files has proceeded as files are completed.

Preliminary work on producing a computer model of the Sydney Coalfield began in 1988. Geological modelling involves generating grids of correlated surfaces (e.g. tops and bottoms of coal seams) from which structure maps, isopach maps and cross-sections can be produced. These maps and sections are used to check the validity of correlations and modify them as necessary. This is an iterative process, with new sets of maps being generated, checked and correlations refined until an acceptable correlation framework is created (Hughes, 1984).

Modelling of the west side of the Sydney Coalfield, west of Sydney Harbour, is in progress (Fig. 1). Data for this area include 272 boreholes, several coastal sections, information from underground mines and topographic and bathymetric mapping. Products from the second iteration show a reasonably good 'fit' without major correlation problems (Fig. 2). Work is continuing on refinement of this part of the model.

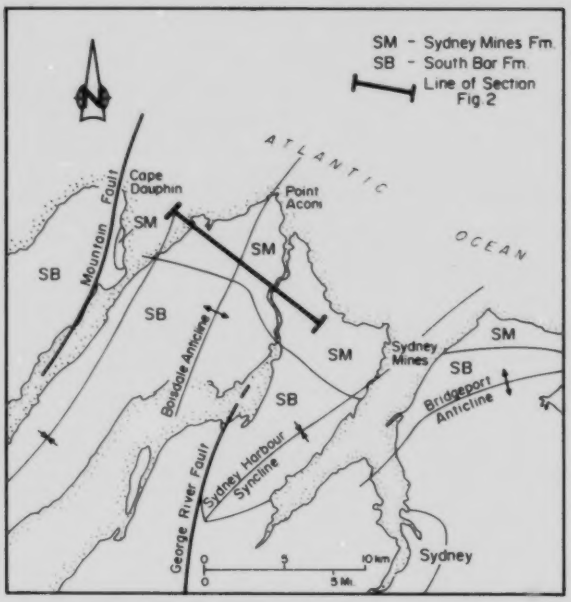

Figure 1. Location map - west side Sydney Coalfield.

Treatment of the New Waterford and Glace Bay areas is beginning and integration and rationalization of the correlation framework will proceed from west to east through the coalfield.

When the Sydney Coalfield model is complete, geological exploration and mining data from the coalfield will be available in a consistently-defined, computer processable format. The digital geological model created from these data will also be available. The model will be an invaluable coal resource management tool, allowing rapid determination of quantity, location and exploitation potential of coal resources according to various combinations of quality, economic, geological and environmental criteria. Planners in industry and government will thus be provided with a flexible, high-resolution resource management tool (Hughes et. al., 1986).

1 Funded by Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement
2 Geological Survey of Canada, Institute of Sedimentary and Petroleum Geology, Calgary, Alberta
3 c/o Energy Resources Division, Nova Scotia Department of Mines and Energy, Halifax, Nova Scotia

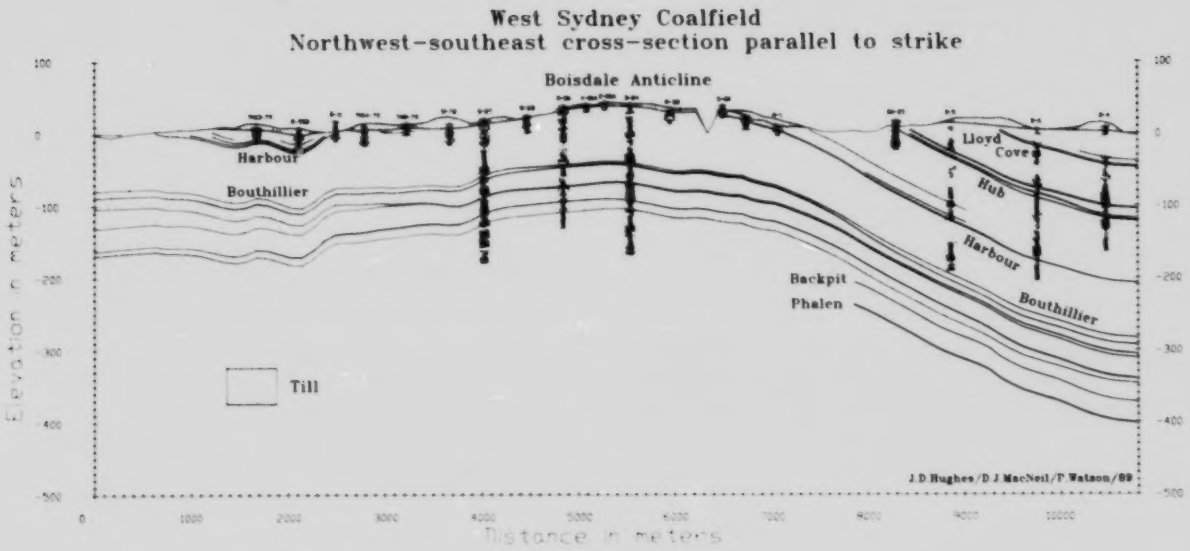

Figure 2. Computer generated cross-section (preliminary) showing structural configuration of coal horizons in west Sydney Coalfield. Borehole data have been projected parallel to the axis of the Boisdale Anticline onto the plane of section for distances of up to 1 km.

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MINERAL EXPLORATION MONITORING

P. D. McCulloch and J. M. McMullin

EXPLORATION ACTIVITY

A downturn in the exploration and development expenditures in Nova Scotia followed the weakening national trend established in mid-1988 and during the first half of 1989. Exploration expenditures for 1989 are currently estimated at $15-20 million, less than half the $40 million spent in 1988.

This decrease in activity is principally due to a significant reduction in gold exploration in the Province. This is attributed to the weakened price of gold and to financing difficulties experienced by many junior companies.

GOLD

Despite the reduction in exploration activity, gold remained the most actively sought metal during the first half of 1989 with much of the exploration work still centred on historical gold districts in Halifax and Guysborough Counties. During the past three record-breaking years gold exploration has focused primarily on known gold occurrences. These occurrences are located in the Cambro-Ordovician metasedimentary rocks of the Meguma Group throughout southeastern and southern mainland Nova Scotia and to a lesser extent in Cambrian and Hadrynian rocks of northern mainland Nova Scotia and Cape Breton Island.

The most advanced gold exploration programs underway in the first half of 1989 included work at Caribou, Moose River and Mooseland in Halifax County and at Forest Hill and Upper Seal Harbour in Guysborough County.

Antioch Resources (N. S.) Limited began a detailed exploration program on the Caribou gold property at the beginning of 1989. Underground bulk sampling, test mining, diamond-drilling, and evaluating previous work on the property are underway to assist in determining potential ore reserves at the Holman Mine. Production ceased in 1946 after being operated by Cominco for 12 years. The mine was dewatered and rehabilitated by Golden Caribou Explorations Limited in 1983 and underground exploration was undertaken in 1987-1988 by Seabright Resources Incorporated.

Seabright Explorations Incorporated, under the direction of Westminer Canada Limited, continued a large-scale surface bulk sampling program on the Moose River gold property (Touquoy zone) to test the potential of a large tonnage, low grade, argillite-hosted ore zone outlined in recent drilling. Westminer Canada Limited (Seabright Division) also continued a detailed evaluation of the Forest Hill gold property, which included additional underground bulk sampling at the Teasdale Mine.

Hecla Mining Canada Limited, in a joint venture agreement with Biron Bay Resources Limited, continued construction of a 125 m shaft on the 'West' zone of the Mooseland gold property in the vicinity of the old workings. Work was suspended midyear when Biron Bay did not to meet its financial commitments.

Orex Exploration Incorporated, in a joint venture agreement with Onitap Resources Incorporated, continued a detailed exploration program at its Upper Seal Harbour Lake gold property near Goldboro consisting of additional surface diamond-drilling and detailed drill core analysis. An agreement was reached with Onitap during the year which will allow Orex to acquire full ownership of the property. The former Boston-Richardson mine shaft was rehabilitated and a new 500 m decline was sunk in 1988. Very favourable results were announced in July 1989.

Inco Ltd. continued its extensive trenching and soil geochemistry work in the Precambrian terrane of the Cape Breton Highlands. Emphasis is presently placed on determining geological controls for widespread gold mineralization.

BASE METALS

Base metals have continued to attract increasing interest, with several exploration programs in progress in a variety of geological environments. Several known occurrences have been re-evaluated with particular emphasis on carbonate-hosted environments of the Lower Mississippian Windsor Group, Hadrynian rocks of the Fourchu Group and

Devonian granites of the South Mountain Batholith.

The lead-zinc deposit in Windsor Group rocks at Jubilee, Victoria County, is being re-evaluated by Falconbridge Ltd. Falconbridge is also conducting regional surveys in Forchu Group metasedimentary and metavolcanic rocks in the Sterling area of Richmond and Cape Breton Counties.

Rio Kemptville Tin Corporation has been conducting mine property and regional surveys for additional tin, copper and zinc reserves in the East Kemptville area, Yarmouth County.

INDUSTRIAL MINERALS

Exploration for industrial minerals including limestone, gypsum and several other commodities has increased moderately in recent years as interest continues to grow in the industrial mineral sector. Exploration has been carried out by limestone, gypsum and aggregate producers to expand reserves both at currently operating quarries and in undeveloped areas. The work done at Kellys Mountain, Victoria County, to identify a major aggregate resource for foreign markets, the developmental planning for a gypsum mine at Dutch Settlement, Halifax County, and limestone/aggregate/building stone research done by this Department at Glencoe, Inverness County, are all significant.

COAL

Esso Resources Limited commenced a new coal exploration program at Springhill, Cumberland County.

DEVELOPMENT ACTIVITY

Westminer Canada Limited (Seabright Division) continued a detailed re-evaluation of the Gays River lead-zinc property during the year including an assessment of previous work. Dewatering of the underground workings commenced in the spring in hopes of re-opening the mine, which was in production from 1979-81, operated by Esso Minerals (Canada Wide Mines division).

Westray Coal Incorporated began the construction of a new underground thermal coal mine at Plymouth, Pictou County, early in 1989. Construction of surface facilities and the driving of two parallel declines to access the coal reserves were in progress when work was suspended at the end of July because of financial considerations.

DRILL CORE LIBRARIES[1]

J. D. Langille

The Nova Scotia Department of Mines and Energy (NSDME) maintains four core library facilities in the Province. Two facilities in Stellarton, Pictou County, are located at the NSDME regional office building on Bridge Avenue and on Acheron Court in the Stellarton Industrial Park. A third facility is on Dakota Drive in the Debert Air Industrial Park, Colchester County, and a fourth facility is near Malagawatch, Inverness County.

Most activity was centred at the main core facility in the Stellarton Industrial Park which consists of four buildings: three older buildings and a new one which opened in 1988. A program was continued in 1989 to consolidate most of the Meguma Terrane drill core into the new building which has provided space to consolidate core from Cape Breton, northern/central Nova Scotia, and southwestern Nova Scotia on a geographical basis in the remaining three buildings.

Less use of all facilities for examination and sampling was made in 1989 than 1988. Most of this slowdown in activity resulted from reduced gold exploration and termination of the Canada - Nova Scotia Mineral Development Agreement at the end of March 1989.

The core libraries staff is permanently stationed in Stellarton and only the Stellarton facilities are staffed on a full time basis. Because most core is stacked on pallets and moved with a staff-operated fork lift truck, some prior notice of an intended visit, usually 24 hours, is appreciated. Visits to facilities outside the Stellarton area should be requested at least 48 hours in advance. For further information on core library activities or requests to visit, please telephone Jim Langille (902) 752-4842 or John McMullin (902) 752-8429, Nova Scotia Department of Mines and Energy, Stellarton.

MINERAL DEVELOPMENT AGREEMENT PROGRAM

Nova Scotia Department of Mines and Energy staff geologist W. Palmer and mineral technician J. O'Leary continued to examine and evaluate diamond-drill core from areas of the Province where substantial drilling has taken place. These evaluations will permit the eventual disposal of surplus core and allow additional packages of core to be received and processed. No large scale disposal of core has taken place to date. Recommendations for disposal of up to 60% of several packages have been put forward for departmental review. No core will be eliminated until companies and other interested parties are informed. Most of this pre-evaluated core will be retained as will approximately 1676 m (5500 ft.) of offshore Cape Breton coal core for which a detailed catalogue was prepared.

During 1989 work proceeded on report preparation and tabulation of drillhole statistics on the Getty Gays River lead-zinc deposit, Colchester County, the Walton barite-base metal deposit, Hants County, the Meaghers Grant area, Halifax County, and the Lake Enon celestite deposit, Cape Breton County. Large packages of core received in 1989 included approximately 7010 m from the Silver Mine/Yava deposit, Cape Breton County.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

INDUSTRIAL MINERALS[1]

J. H. Fowler

Nova Scotia's industrial mineral producers have been shipping industrial minerals for more than 200 years. This industry continues to be competitive in today's markets by maximizing resource utilization and taking advantage of the Province's strategic geographical location to access world markets.

There are 18 industrial mineral producers operating at 31 sites in Nova Scotia. Ten commodities are extracted, including anhydrite, barite, clay, shale, dolomite, gypsum, limestone, peat moss, salt and silica sand. Nova Scotia also has a major aggregate industry operating in both granular and bedrock deposits.

Many of the commodities produced are shipped to markets in other regions of Canada, the United States, the Caribbean, Western Europe, the Middle East and Japan. Unprocessed materials shipped include aggregate, salt and gypsum. Manufactured or processed materials shipped include pharmaceutical barite, cement, plaster of paris products, clay products, food and chemical grade salt and peat moss products.

The total value for industrial mineral products including secondary processing for 1988 was over $250 million and direct employment in the industry was 1800.

Some of the more significant developments in 1988-89 were:

(1) Construction of a $65 million fibre gypsum board plant at Point Tupper, Richmond County by Louisiana-Pacific Corporation. Start-up of this plant is scheduled for early 1990.

(2) Announcement by Municipal Ready-Mix of Sydney River, Cape Breton County of their interest in developing an aggregate quarrying and marine bulk loading operation at Kellys Mountain, Victoria County.

(3) Improved marine shipping of salt from The Canadian Salt Company Limited mine at Pugwash, Cumberland County. In June 1989, a large self-unloading barge, the Captain Edward V. Smith, capable of carrying significantly larger shipments of salt out of Pugwash began service. The barge is owned by Keybulk Transportation of Montreal.

(4) Gypsum shipments for 1988 recorded at just over 7 million t, the highest on record.

RESOURCE PROMOTION STUDIES COMPLETED

Nova Scotia Department of Mines and Energy, Open File Report 88-056 *An assessment of the hydrocarbon and compressed air storage potential of Nova Scotia salt deposits*, by Nolan Davis and Associates (N. S.) Limited, 1988, 195 pages.

Nova Scotia Department of Mines and Energy, Open File Report 88-063 *An Assessment of the hydrocarbon and compressed air storage potential of Nova Scotia salt deposits*, by Nolan Davis and Associates (N. S.) Limited, 1988, 22 pages.

CONVENTIONS, MEETINGS AND SEMINARS

(1) Review of Industrial Mineral Activities in Nova Scotia, by John H. Fowler. Presented at the Federal/Provincial Meeting of Industrial Mineral Specialists, Ottawa, Ontario, October 12 and 13, 1989.

(2) Industrial Mineral Mining and Development Opportunities in Nova Scotia, by John H. Fowler. Presented at 57th Annual Meeting and Convention of the Prospectors and Developers Association of Canada, Toronto, Ontario, March 5-8, 1989.

(3) Aggregate Resources in Nova Scotia, by John H. Fowler. Presented at the Aggregates Seminar/Workshop sponsored by The Technical University of Nova Scotia Continuing Education Division, Halifax, April 1 and 2, 1989.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

GYPSUM/ANHYDRITE PROJECT[1]

G. C. Adams

Since its inception in June 1985 the Gypsum/Anhydrite Project has had three objectives. The first was to develop a comprehensive inventory of the Province's gypsum and anhydrite resources,- the second was to establish a working rapport between the Department and the Province's current producers, and the third was to initiate and encourage development of more diverse ways to utilize Nova Scotia's gypsum and anhydrite resources.

Field checking of surficial exposures was completed during the 1988 field season. Since that time information has been compiled on an occurrence by occurrence basis using field data, assessment reports, open file maps, open file reports and theses available in the Department. Preliminary write-ups for all occurrences are near completion at this time and a final report will be finished in 1990.

Occurrence write-ups will be arranged by counties in the final report. They will provide the reader with a synopsis of the most recent information available on each particular area with respect to geological setting, field observations, subsurface intersections (where available), thickness of overburden, depth of hydration and quality of material where available. Additionally, information with regard to property ownership or gypsum lease holdings is included where relevant. This information is in a format to assist those interested in exploration and development to select areas having the greatest potential, as well as those individuals merely interested in knowing where occurrences can be found.

Production of gypsum and anhydrite by quarries in the Province continued to increase in 1988. Also of note in 1988 was the announcement that Louisiana Pacific Corp. would construct a gypsum paper-fibre composite wallboard plant at Point Tupper, Richmond County. Plant construction is presently underway, on schedule and due to be complete by early 1990.

Research, funded by the Canada-Nova Scotia Mineral Development Agreement, on anhydrite plasters is currently underway at the Technical University of Nova Scotia. This work is an extension of studies into the use of local anhydrite for roadside packing materials in coal mines (see next paper, this volume). The current investigations are focusing on board products and screed flooring and should be completed before the end of 1989.

All three objectives of the Gypsum/Anhydrite Project, as established in 1985, will have been met by year's end. Additional, more detailed work (i.e. drilling), should be carried out on selected occurrence areas having the most development potential. Further research projects will probably develop in the area of alternate utilization of gypsum and anhydrite as current research progresses. Continued cooperation between the Department and the Province's active gypsum industry may also lead to further successes such as the soon to be opened wallboard plant at Point Tupper.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

NSDME Report 89-3

ANHYDRITE-BASED UNDERGROUND COAL MINE CONSTRUCTION MATERIALS[1]

G. C. Adams

Anhydrite shipments in Nova Scotia in 1988 totalled 141 717 t. Two of the Province's six gypsum producers market anhydrite to the agriculture and cement industries with most of this material being consumed offshore. Small amounts of crushed anhydrite are sold in the Province as soil conditioner or as driveway gravel. By comparison these same producers shipped 7 017 273 t of gypsum in 1988.

While production and shipments of gypsum far exceed those of anhydrite in Nova Scotia the relative abundance of these two minerals is exactly the opposite. Virtually all gypsum deposits in the Province are underlain by massive deposits of anhydrite. Potential reserves are in the order of billions of tonnes.

Literature research conducted in early 1986 determined that anhydrite had been used in West German coal mines for up to 15 years as a construction material for gateside packs, stoppings and roadway backfilling. A plan was proposed by staff at the Technical University of Nova Scotia and Nova Scotia Department of Mines and Energy to determine whether indigenous anhydrite could be used as a construction material in the coal mine operations in the Sydney Basin of Nova Scotia.

Late in 1986 a Project Identification and Annual Plan (PIAP) was submitted which proposed that research be carried out at the Technical University of Nova Scotia (TUNS) on anhydrite products. The PIAP was given approval in late 1987 for funding through the Mineral Development Agreement (MDA) with the Canada Centre for Mineral and Energy Technology (CANMET) as administrator.

Utilizing limited information gained through published reports from West Germany and the United Kingdom, research was conducted on anhydrite samples taken from the following sites: (1) Georgia Pacific Corp., Sugar Camp, Inverness County; (2) Little Narrows Gypsum Co. Ltd., Little Narrows, Inverness County; (3) National Gypsum (Canada), Ltd., East Milford, Halifax County; and (4) Fundy Gypsum Co. Ltd., Wentworth, Hants County. Test variables included particle size ranges, water to solid ratios and chemical accelerator types and quantities.

Laboratory testing consisted of uniaxial compressive strength tests on various anhydrite/accelerator/water mixes that were cast in moulds to form blocks which simulate *in situ* loading conditions on anhydrite packs in coal mines. No standards for testing anhydrite materials currently exist in North America. The TUNS efforts were greatly assisted, however, by information gained from the West German coal mine research institute, Bergbau-Forschung GmbH.

Results of these tests showed that if properly prepared, anhydrite from Little Narrows Gypsum Co. Ltd. could perform as well as, or better than known European anhydrite products. During the latter stages of the research at TUNS interest was shown in the project by Cape Minerals Ltd. of Sydney, Cape Breton County. Cape Minerals decided to promote the idea to the Cape Breton Development Corporation (DEVCO) as a means of replacing the more expensive imported materials like hardwood chocks and portland cement-based monolithic packing materials presently in use. In order to achieve this end, Cape Minerals Ltd. acquired the raw materials and capital equipment required to perform a surface trial at their facilities at Sydport Industrial Park, Point Edward, Cape Breton County. Financial assistance for this project was provided by the Department through the MDA's Mineral Investment Stimulation-MDA's Program (MISP).

Early in June 1989 the surface trial of the anhydrite-based gateside pack system (Fig. 1) was carried out at Cape Minerals Ltd.'s facilities located in Sydport Industrial Park. Visiting officials of the anhydrite supplier (Little Narrows Gypsum Co. Ltd.) and the potential consumer (DEVCO) attending the trial were encouraged by the results and contracted Cape Minerals Ltd. to conduct an underground trial. At the time of

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

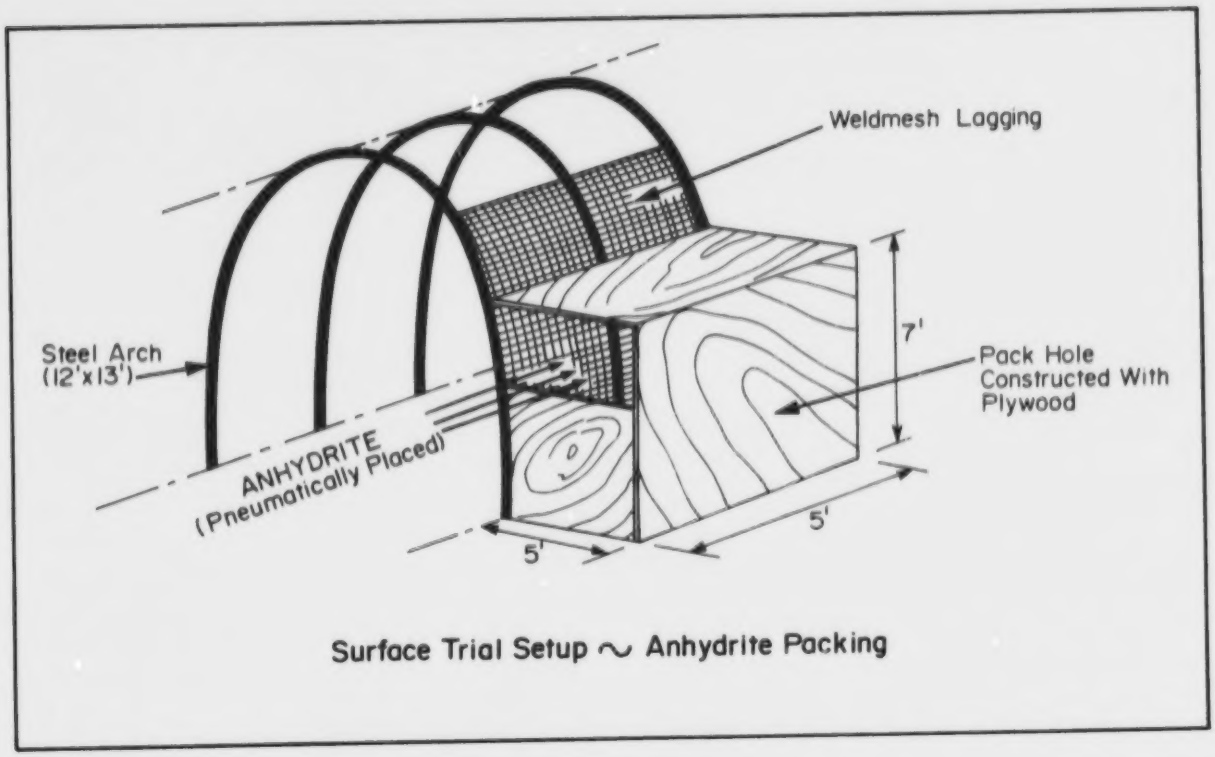

Figure 1. Surface trial setup of anhydrite packing.

writing this report an underground trial comprising 300 tonnes of anhydrite-based gateside pack is underway at the Lingan Colliery in New Waterford, Cape Breton County.

The research into anhydrite at TUNS also included the potential to produce anhydrite plasters. Results of this preliminary investigation were encouraging and subsequently led to additional research that is currently underway at TUNS. This research includes investigation of anhydrite-based plaster board products as well as floor screeds and is funded by MDA with administration by CANMET.

AGGREGATE PROJECT[1]

G. Prime

Completion of 1:50 000 scale aggregate maps covering Cumberland and Colchester Counties was accomplished during 1989. This included the field checking of several aggregate deposits discovered in the late stages of the program. In addition to the maps, a database was compiled on the deposits, pits and quarries in the region. This includes not only work done in this study, but test results documented in previous Nova Scotia Department of Mines and Energy and Department of Transportation reports. This information will be available on open file shortly.

An abundance of new glacio-fluvial deposits, consisting primarily of eskers and kames, have been identified in the Cumberland-Colchester region. Many of these are of good quality and occur in areas where resource depletion or absence is a problem. Some of the more accessible deposits were excavated and sampled late in 1988.

A type of modern stream deposit recognized in this study as having good aggregate potential is the alluvial fan deposit. Hughes (1956) first documented and described postglacial alluvial fans in the southern part of the region near Shubenacadie. Subsequent work by Stea et al. (1985) identified many of these deposits in the Parrsboro area although no genetic distinction was made between these materials and other modern stream deposits. The present study reveals that the deposits are quite common in some areas of northern Nova Scotia.

The alluvial fans appear to have developed immediately following deglaciation and prior to the return of vegetation and stream incision. They occur as small conical-shaped wedges of gravel which were deposited where high-gradient tributary streams in the hills or uplands emptied onto lowland plains or valley floors. The abrupt loss of stream competence at this juncture caused the streams to deposit their coarse materials.

Sampling of the fans indicates that they are composed of poorly-stratified, well-sorted channel gravels. It also appears that at least some deposits may contain coarse, poorly-sorted debris flow units in proximal areas. The source of the detritus in the deposits is almost exclusively of igneous and metamorphic origin, therefore, in general they should contain the competent materials necessary to produce high quality aggregate. Although the deposits are small, they may offer alternative potential in areas where good gravel is difficult to find. An example of this is the Parrsboro area (Fig. 1) where the large glacial outwash deposits are relatively low in quality compared to the alluvial fan deposits.

The bedrock aggregate potential of northern Nova Scotia is good in the Cobequid Highlands, due to an abundance of granite, quartzite, and volcanic rocks. Younger rocks in the Carboniferous basins, which offer potential as aggregate, include some of the Windsor Group carbonates, Carboniferous and Triassic polymictic orthoconglomerate and Triassic basalt.

Particularly interesting is the polymictic conglomerate of the Cumberland Group, including the Claremont Formation and Polly Brook Formation. The petrographic composition of some of these conglomerates is predominantly igneous and metamorphic rock types. Furthermore many of the conglomerate units are quite clean and clast-supported, characteristics that should make them suitable for processing as highway materials. Although the conglomerate is widely distributed north of the Cobequids, the areas with the best potential will be limited to those (1) lacking conventional aggregate sources, (2) having conglomerate with clast-supported basement complex rock types, (3) having conglomerate units with dimensions worth mining, and (4) containing low-angled to flat-lying strata. More work will be required in the future to fully assess their potential.

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1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

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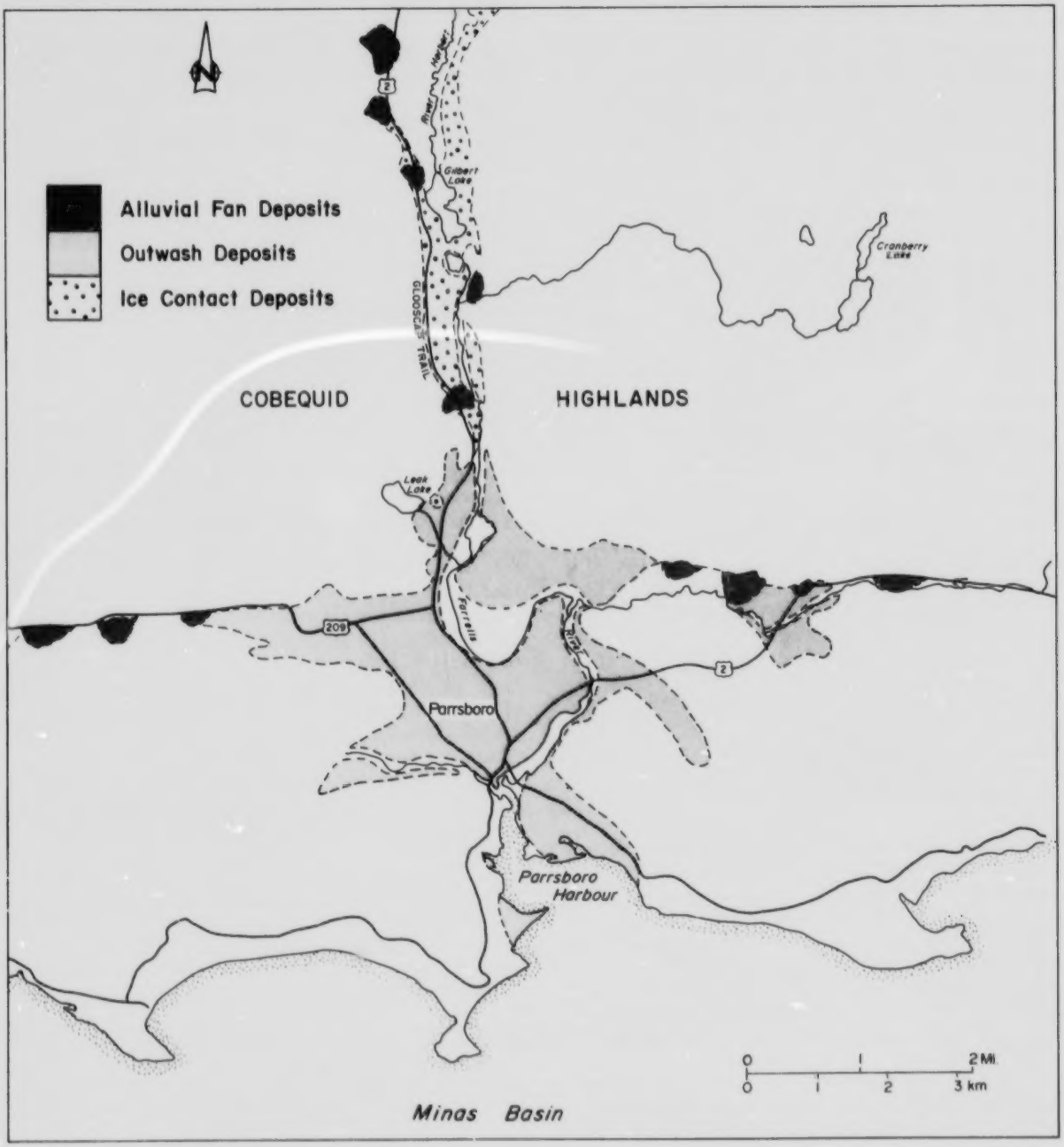

Figure 1. Granular aggregate deposits of the Parrsboro area.

BUILDING STONE PROJECT[1]

G. B. Dickie

1989 FIELD PROGRAM

Erinville, Guysborough County, and South River Lake, Antigonish County

Black granite was produced in the mid 1930s and early 1960s at Erinville, Guysborough County, and South River Lake, Antigonish County. Several gabbro to diabase plugs occur in southern Antigonish County and northern Guysborough County between Copper Lake and Erinville. The gradiometer maps of the area suggest the presence of mafic bodies in many locations. The areas were prospected to determine the extent and quality of the gabbro plugs. Many of the magnetic anomalies prospected were not caused by gabbroic plugs. Others of gabbroic composition were not suitable for building stone due to chloritic alteration or the presence of pyrite and pyrrhotite. Prospecting and mapping also suggested that the gabbro plug mapped at West Erinville and extending west to Hoppenderry is a small circular-shaped body, possibly only 1 km in diameter and centred just east of Kelly Lake.

A five hole drilling program (172.2 m) was carried out on the Erinville plug. The first hole drilled in the old Arsenault Quarry cut more than 60 m of fresh fine- to medium-grained dark grey gabbro to diabase. A second hole collared 500 m west and 40 m above the first, intersected over 40 m of highly chloritized medium grained gabbro underlain by less altered gabbro. Two other holes located on the northern and southern sides of the plug intersected black slate. The results of this work suggest that the Erinville gabbro body contains some unaltered dark grey rock which may be suitable for building stone. More drilling and trial quarrying is required to prove the presence of an economic building stone deposit.

One hole (59.1 m) near the old quarry at South River Lake, Antigonish County, intersected a strongly chlortic, medium grained, dark grey gabbro. Numerous serpentine and talc veins were observed in the core making it unfit for building stone.

Nictaux and South Williamston, Annapolis County

The grey granodiorites in the Nictaux area of Annapolis County have been quarried for monument stone for over 100 years. Erratic joint spacing, the presence of quartz and pegmatite veins and xenoliths or 'black knots' make quarrying difficult. Heritage Memorials Ltd. presently quarry the Nictaux stone for use as monument blanks and base stock. Known reserves in this quarry were being depleted and drilling information was required to find additional reserves. Three holes totalling 116.8 m were drilled by the Nova Scotia Department of Mines and Energy in February 1989 in the Nictaux Quarry.

The results of this work eliminated one area of the quarry as a source of building stone due to discolouration of the rock by alteration. Two other areas were found to contain similar rock to that presently being quarried. The joint frequency, however, does not decrease significantly with depth so little is to be gained from quarrying deeper.

A grey granodiorite similar to the Heritage stone was found 1.5 km north west of the Nictaux Quarry on the farm of Robert Baltzer (1989), South Williamston, Annapolis County. The Nova Scotia Department of Mines and Energy drilled three holes totalling 62 m on the Baltzer property. Two of the holes cut granite of similar colour and quality as the Heritage stone. The third hole intersected a highly altered and fractured granodiorite, unsuitable for use as building stone. The fracture and joint density on the Baltzer property is similar to the other quarries in the Nictaux area. It is very difficult to obtain blocks over 5 t and the quarry waste factor is often over 75%.

Hammonds Plains, Halifax County

A property located at Hammonds Plains, Halifax County, owned by Vernon Kynock (1988)

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was mapped, sampled and tested for use as an aggregate quarry. The results of this work outlined a large tonnage of quartzite suitable for asphalt and concrete aggregate. The results of this study are detailed in Nova Scotia Department of Mines and Energy, Open File Report 89-002.

PUBLICATIONS

A comprehensive catalogue of Nova Scotia Dimension Stone, Catalogue 89-01, and its companion publication *Nova Scotia Building Stone for Designers, Developers and Quarriers*, Information Series No. 19, was completed and released. They catalogue actual stone samples of 11 Nova Scotia building stones with a full colour booklet describing the Nova Scotia building stone industry. The final report on Nova Scotia Building Stone will be completed in 1989.

Nova Scotia Department of Mines and Energy Open File Report 89-006, a report identifying the source of dimension stone used in the construction of the Dominion Building, was also prepared and released in 1989.

TECHNICAL SESSIONS

A presentation on Nova Scotia building stone was made to the Nova Scotia Association of Architects at White Point, Queens County, in September 1988. A presentation on the same subject was made at the Cleaning and Restoration of Stone and Masonary Seminar/Workshop sponsored by the Technical University of Nova Scotia, Continuing Education Department, in May 1989. The author attended the StonExpo'89 Trade Show and Convention in New Orleans in March 1989. This is one of the world's largest building stone trade shows and interest in Nova Scotia stone was expressed by many delegates.

VARIOUS COMMODITIES PROJECT[1]

R. MacDonald

The Various Commodities Project, initiated in May 1986 and funded under the Canada - Nova Scotia Mineral Development Agreement, has attempted to identify and increase the database on several industrial mineral commodities occurring in Nova Scotia and presently sought in the market place. The project geologist has also served as a resource information person for companies operating in the Province who wish to increase their ore reserves and also for companies who are interested in establishing operations in Nova Scotia.

SUMMARY OF INVESTIGATIONS

Much of the project focused on investigating deposits with the greatest potential for development such as high-grade, large tonnage deposits of limestone and dolomite. Some of these large deposits on Cape Breton Island also received special attention from cement, aggregate and power companies. A number of smaller, high-grade deposits on mainland Nova Scotia were explored and bulk sampled for special applications testing.

The Chegoggin Point, Yarmouth County, silica and garnet deposit has been explored by geophysical surveys and diamond-drilling. Interest in this property has led to the issuing of a special licence to a private exploration company for further work.

The database on provincial deposits of andalusite, titanium, talc, barite, mica and garnet has been greatly improved. Additional work is necessary on some of these occurrences and on other commodities for which the market is temporarily depressed.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

LAND USE POLICY DEVELOPMENT PROJECT[1]

D. B. Hopper

The Nova Scotia Department of Mines and Energy is attempting to encourage a greater awareness of the Province's mineral and energy reserves among many land users, planners and other land use policy decision-makers. A Land Use Project has been building toward a provincial policy with respect to mineral and energy lands. The underlying principle will be to ensure that resource and land use decisions are made with the most recent knowledge of mineral, aggregate and energy resource potential.

Through the Canada - Nova Scotia Mineral Development Agreement the Land Use Policy Development Project is channelling resource information to the provincial and municipal planning communities. The overall objective is to promote proper management and protection of mineral resources and surface land access by providing resource information, improved communication and resource management guidance to all land use managers.

Since the Province's land base is being shared by numerous land and resource users, an integrated approach to resource management, ensuring protection of the environment, is preferred over traditional sectoral resource planning. All maps and written materials produced by the Land Use Project are designed to easily adapt to research and background studies for other resource and land use planning strategies. The Department sees the need for a more judicious selection of land for multiple and sequential uses, based on knowing areas of high mineral potential, especially during the process of developing land use plans. In this regard the Land Use Project is producing information for input to resource and land use strategies so that optimum access to land above Nova Scotia's mineral, aggregate and energy reserves remains available.

LIMITED ACCESS TO LAND FOR EXPLORATION

The issue of decreasing land access for mineral exploration and development is a growing concern for the mineral resource sector. Nearly 15% of the provincial land base either prohibits access or has high potential for restricting access to land for exploration. Currently, 7% of the Province's land base remains completely off limits to all mineral based activity. These lands are largely made up of federal crown lands, uranium moratorium areas and protected ecological sites. An additional 8% of Nova Scotia is made up of special use lands identified for various biophysical, historical or cultural characteristics. Furthermore, 70% of the Province is privately owned and the right of access to all lands in Nova Scotia must be gained with permission from the landowner.

SURVEY ON MINERAL RESOURCES AND LAND USE ISSUES

Results of a survey on mineral resource and land use issues have been compiled and discussed in a background report by the Land Use Group. The survey results will be released as a Nova Scotia Department of Mines and Energy Open File Report next year.

MINERAL RESOURCE LAND USE MAPPING

The Land Use Policy Development Project is providing Nova Scotia's municipalities with mineral resource land use mapping and other materials for input to the municipal land use planning process.

Mineral Resource Land Use maps have been compiled and released as Nova Scotia Department of Mines and Energy Open File Maps (OFMs) for the following areas:

Halifax County (OFM 88-01 to 88-12)
Hants County (OFM 88-17 to 88-22)
Cape Breton County (OFM 88-33 to 88-38)
and Kings County (OFM 88-44 to 88-49)

Map sets in the preliminary stage of compilation include Lunenburg County (OFM 89-04 to 89-09) and Pictou County.

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OTHER WORK CARRIED OUT BY THE LAND USE GROUP:

Aquaculture

The Land Use Group has the additional responsibility of reviewing applications for aquaculture licenses and experimental permits. This review process allows the Department to screen proposed aquaculture sites for potential conflict with the exploration and mining sector. This is in keeping with the necessity to monitor all land and near-shore resource activity to maintain a conflict-free land management practice.

Mineral Resources and Planning

The Land Use Group receives requests for mineral resource information from planners and planning consultants. Reports and maps have been prepared with current mineral resource information for input to specific land management plans and municipal plan strategies.

Provincial Planning

The Land Use Group also contributes to activities and developments in provincial planning. Along with providing input to papers and policy produced by the interdepartmental committee on land use, the group is active on Voluntary Planning's Land Resources Coordinating Committee. Staff also record and monitor changing land use, such as designations of ecological reserves and surface water supply watersheds.

MINERAL INVENTORY

N. A. Lyttle

BIBLIOGRAPHIC DATABASE ACTIVITIES[1] (J. M. Freeman, P. Hartling, D. Robar, S. Saunders)

Indexing and on-line data entry into GEOSCAN continued throughout the period August 1, 1988, to July 31, 1989, for Nova Scotia Department of Mines and Energy (NSDME) bibliographic records. GEOSCAN is a bibliographic database which provides access to publicly available geoscience literature concerning the Canadian landmass and offshore regions. The database presently contains over 109,500 records, and is co-operatively produced from the indexing contributions of 12 federal, provincial and professional geoscience organizations located throughout Canada. The Geological Survey of Canada, through the National GEOSCAN Centre, co-ordinates these indexing activities and provides computer resources in support of this project.

During the period August 1, 1988, to July 31, 1989, 732 new NSDME records were added to GEOSCAN. These records consisted of 420 assessment reports, 42 open file maps, 30 open file reports, 139 publications, 92 theses and 9 journal literature references, representing a 7.4% increase in the Nova Scotia component of the database. As of July 31, 1989, the database contained 10,582 NSDME records consisting of 4626 assessment reports, 2122 publications, 1275 journal literature references, 1003 open file maps, 868 open file reports and 688 theses.

The bibliographic index, Report 88-2: *Index to Publications, Open File Reports and Open File Maps for 1987* was released in September 1988. Report 89-2: *Index to Assessment Reports, Open File Maps, Open File Reports and Publications for 1988* was released in October 1989.

METALLIC MINERAL OCCURRENCES DATABASE ACTIVITIES[1] (G. DeMont)

In order to improve the quality and reliability of information in the Metallic Mineral Occurrences data cards and database, the program of systematic reference researching and checking, coupled with selected field checking, continued over the period August 1, 1988, to July 31, 1989. During this period, 198 metallic mineral occurrence data cards were researched and checked and limited field checking was conducted in parts of the Cobequid Highlands, the Antigonish Highlands and Cape Breton Island. One hundred and fifty cards were revised and updated, 48 cards were eliminated from the dataset and 21 new metallic mineral occurrences were documented. Since this program began in fiscal year 1987-88, a total of 572 metallic mineral occurrence cards have been researched and checked, 471 newly revised and updated cards have been generated, 101 cards have been eliminated from the dataset and 36 new metallic mineral occurrences have been documented, covering the following maps sheets: 11E, 11F/05, 11, 12, 13 and 14, 11K/01, 02, 04, 06, 10 and 11, 21A/10 and 21H.

A new metallic mineral occurrences database, based on the information in the revised metallic mineral occurrences cards, has been created using Advanced Revelation as the database management system software. Ninety-nine metallic mineral occurrence records have been entered into this database as of July 31, 1989.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

AUTOMATION IN THE MINERAL DEVELOPMENT DIVISION[1]

L. Crust

BACKGROUND

The computing resources of the Mineral Development Division of the Department of Mines and Energy have increased substantially during the past fiscal year.

The local area network in our Halifax office has been expanded, with the upgrading of the file server to a Compaq Deskpro 386/25 with a 300 megabyte hard disk, and with the addition of four workstations (including one workstation in the Mining Engineering Division), bringing the total number of workstations to eight. The Stellarton office has received an additional Compaq Deskpro 286 with a 130 megabyte hard disk, giving that office a total of three microcomputers, allowing one to be used in the Core Library.

Most employees of the Halifax office of the Division have some experience using the computers, and with the flexibility offered by the local area network workstations are in almost constant use. The microcomputers in Stellarton are also being heavily used by all departmental staff at the regional office.

The computers in both offices are being used for database management (using Advanced Revelation and DBASEIII Plus), spreadsheet (using Lotus 1-2-3), communications (using Crosstalk XIV and Crosstalk Mark 4), and word processing (using Word Perfect) applications.

Several new developments during 1988-89 include:

(1) the purchase by the Industrial Minerals Group of a turnkey system of hardware and software which it is using, with the Mining Engineering Division, for the evaluation of mine economics;

(2) the development of a database and cataloguing/indexing system for the Library; and

(3) the purchase by the Word Processing Group of Perfect Pitch, which allows our Micom 3004 word processor to communicate directly with a workstation on our local area network.

WORK IN PROGRESS

Work in progress includes the development of a Mineral Rights database within Advanced Revelation, which will serve as the basis of record keeping for the Mineral Rights Registry. Work is also continuing on a number of other in-house databases, including databases for the Library, and for the Nova Scotia component of GEOSCAN.

A new workstation is being purchased for the Mineral Rights Registry, and four workstations from other divisions are being added to our network, bringing the total number of network stations to thirteen.

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PRELIMINARY RESULTS OF RB/SR AND $^{40}AR/^{39}AR$ GEOCHRONOLOGICAL INVESTIGATIONS, EAST KEMPTVILLE LEUCOGRANITE, SOUTHWESTERN NOVA SCOTIA: EVIDENCE FOR A CA. 370 MA AGE OF EMPLACEMENT AND MULTIPLE TECTONO-THERMAL OVERPRINTING EVENTS[1]

D. J. Kontak, R. F. Cormier[2] and P. H. Reynolds[3]

INTRODUCTION

The East Kemptville leucogranite (EKL) is a uniform phase of muscovite-topaz leucogranite that outcrops in the western extremity of the ca. 370 Ma peraluminous South Mountain Batholith (SMB). The age and petrogenesis of the EKL are particularly significant because it hosts the East Kemptville Sn-Zn-Cu-Ag deposit (56 million tonnes of 0.165% Sn) and, therefore, a thorough understanding of the deposit environment has important implications for exploration of similar mineralization both within the immediate vicinity of the EKL and in other parts of the SMB. The geological setting and petrology of the EKL have been examined in detail elsewhere (Kontak et al., 1986; Kontak, 1987; Kontak, under review) and in this communication we discuss the results of recent Rb/Sr and $^{40}Ar/^{39}Ar$ analyses designed to determine the age of the EKL.

REGIONAL AND LOCAL GEOLOGICAL SETTING

The EKL occurs as part of the Davis Lake Pluton (DLP*), a subcircular intrusive complex dominated by coarse grained leucomonzogranite with lesser amounts of leucogranite (e.g. EKL) and muscovite-biotite monzogranite. All the aforementioned rocks are enveloped by a coarse grained biotite monzogranite phase (Fig. 1a). It is important to emphasize here that pervasively developed within the DLP are deformational fabrics of both brittle and ductile nature. Two zones where this deformation is regionally extensive are shown on Figure 1a as the East Kemptville Shear Zone (EKSZ; O'Reilly, 1988) and the Rushmere Lake Shear Zone (RLSZ; Smith, 1985) (Fig. 1a). Both of these zones are northeast-trending structures of regional extent that transect the EKL, DLP and Lower Paleozoic metasedimentary rocks of the Meguma Group. Rocks within these structures show several well developed tectonic fabrics of unresolved ages. The presence of this deformation is emphasized because it has previously gone unreported, prior to the current activities of Nova Scotia Department of Mines and Energy staff, and its potential influence on the results of Rb/Sr and Ar-Ar investigations has not been considered.

The detailed geological setting of the EKL is discussed elsewhere (Kontak, 1987; Kontak et al., 1986) and only the salient aspects are repeated here. Much of the deposit area (Fig. 1b) is underlain by relatively fresh (see Kontak (1987) for discussion), unmineralized leucogranite that is variably deformed. Structural fabrics observed in both outcrop and thin section examination indicate that highly variable amounts of penetrative ductile deformation affected the EKL subsequent to emplacement and mineralization. It is highly possible that more than one period of deformation may have affected these rocks but further detailed work is required in order to establish a chronology of events.

PREVIOUS GEOCHRONOLOGICAL DATA FOR THE EKL AND DLP

Results of previous geochronological investigations of the DLP and EKL, as reported by Reynolds et al. (1981), Zentilli and Reynolds (1985), Richardson (1988b) and Richardson et al. (1987, 1988a, 1988b), are summarized in Figures 1 and 2. These data may be collectively interpreted to indicate the following: (1) the age of the DLP is defined as ca. 370 Ma based on concordant biotite and muscovite $^{40}Ar/^{39}Ar$ ages (Fig. 1a). This age

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement
2 Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia B2G 1C0
3 Department of Geology, Dalhousie University, Halifax, Nova Scotia B3H 3J5

*Note that the terminology of Richardson (1988a, 1988b) and Richardson et al. (1987) used for this part of the SMB is replaced by new geological definitions assigned by MacDonald et al. (1988, 1989). For example, Davis Lake Complex is now Davis Lake Pluton.

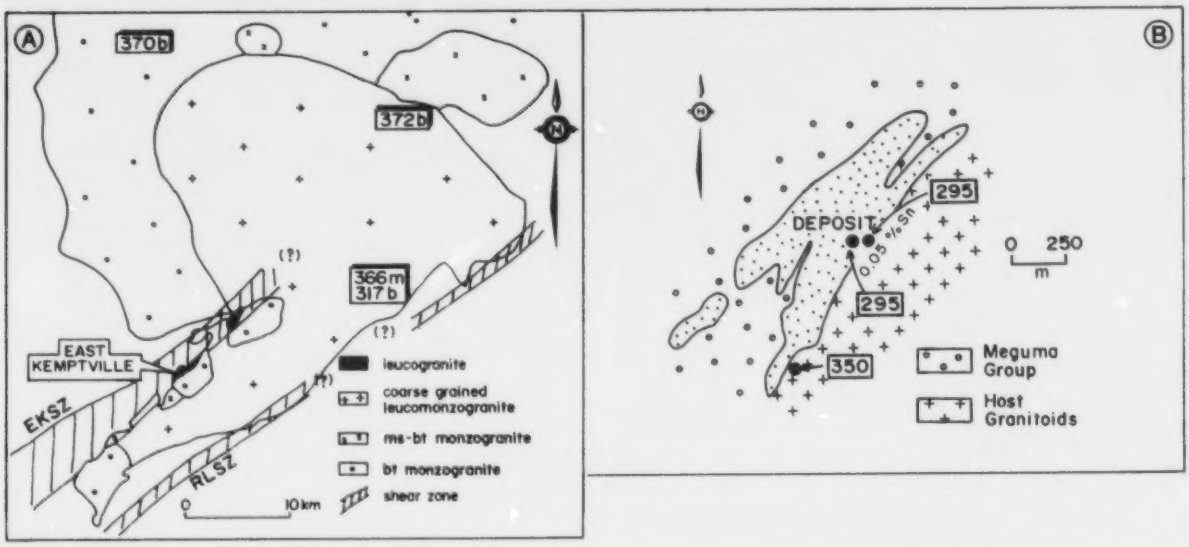

Figure 1. (a) Regional geological setting of the East Kemptville leucogranite in the western half of the South Mountain Batholith (geology after MacDonald et al., 1989). The ages refer to 40Ar/39Ar analyses of micas (b=biotite, m=muscovite) reported in Reynolds et al. (1981). EKSZ=East Kemptville Shear Zone (after Kontak et al., 1986 and O'Reilly, 1988, RLSZ=Rushmere Lake Shear Zone (after Smith, 1985). (b) Outline of the East Kemptville deposit area (approximately equal to the area underlain by EKL) and location of samples dated by Zentilli and Reynolds (1985). Note that the mica ages shown represent inferred plateau ages.

is similar to additional $^{40}Ar/^{39}Ar$ and Rb/Sr data for the rest of the SMB as reported by Reynolds et al. (1981, 1987) and Clarke and Halliday (1980), respectively, and suggests a comagmatic history. (2) Pervasive redistribution of Rb and Sr occurred in the DLP at ca. 330 Ma based on the data of Richardson and co-workers (Fig. 2a). The Rb/Sr data are not considered to reflect the primary crystallization age of the DLP, as these authors have stated, but instead a subsequent tectono-thermal event. Further evidence for the presence of one or more thermo-tectonic events is indicated by: (i) the young $^{40}Ar/^{39}Ar$ biotite age for a sample collected from the southern margin of the DLP near the RLSZ (see Fig. 1a); (ii) the young (i.e. ca. 250 Ma) whole rock-biotite ages (n=4) reported by Richardson (1988b) for samples from the DLP (Fig. 2a); and (iii) the discordant $^{40}Ar/^{39}Ar$ muscovite age spectrum (Figs. 1b and 2c) for sample 79-114, a deformed muscovite-biotite monzogranite, collected near the EKL. (3) The EKL and associated lithophile element mineralization have a minimum age of 337 Ma based on whole rock Rb/Sr analyses of the greisens by Richardson et al. (1988b). That this age may reflect a time of redistribution of Rb and Sr, rather than the true age of crystallization of the EKL as Richardson et al. (1988a) suggest, must be considered as a real possibility in light of the above interpretation of the Rb/Sr data for the DLP. (4) A thermal overprinting event at ca. 295 Ma is recorded by $^{40}Ar/^{39}Ar$ age spectra for two greisen muscovites reported by Zentilli and Reynolds (1985) (Figs. 1b and 2c).

The aforementioned radiometric data for the EKL and DLP indicate a complex magmatic-thermal-tectonic evolution for the area. However, additional radiometric data for southwestern Nova Scotia by Reynolds et al. (1987), Dallmeyer and Keppie (1987, 1988), Muecke et al. (1988), Cormier et al. (1988) and Soehl et al. (1989) substantiate these findings and collectively indicate that most of the aforementioned events were regional in extent.

METHODS

Rb and Sr isotopic analyses of EKL were performed by R. F. C. at St. Francis Xavier University (see Cormier et al. (1988) for analytical details). Selected for analyses were 10 whole rock powders of fresh EKL; from 4 of these samples, additional Rb/Sr data were obtained for the whole rock minus the muscovite fraction as well as mineral concentrates (muscovite, alkali feldspar and quartz-plagioclase). $^{40}Ar/^{39}Ar$ analysis of a single muscovite separate from fresh EKL was obtained by P. H. R. (see Reynolds et al. (1987) for analytical details) at the Dalhousie University Ar isotope laboratory. Theoretical principles of the Rb/Sr and $^{40}Ar/^{39}Ar$ techniques are discussed

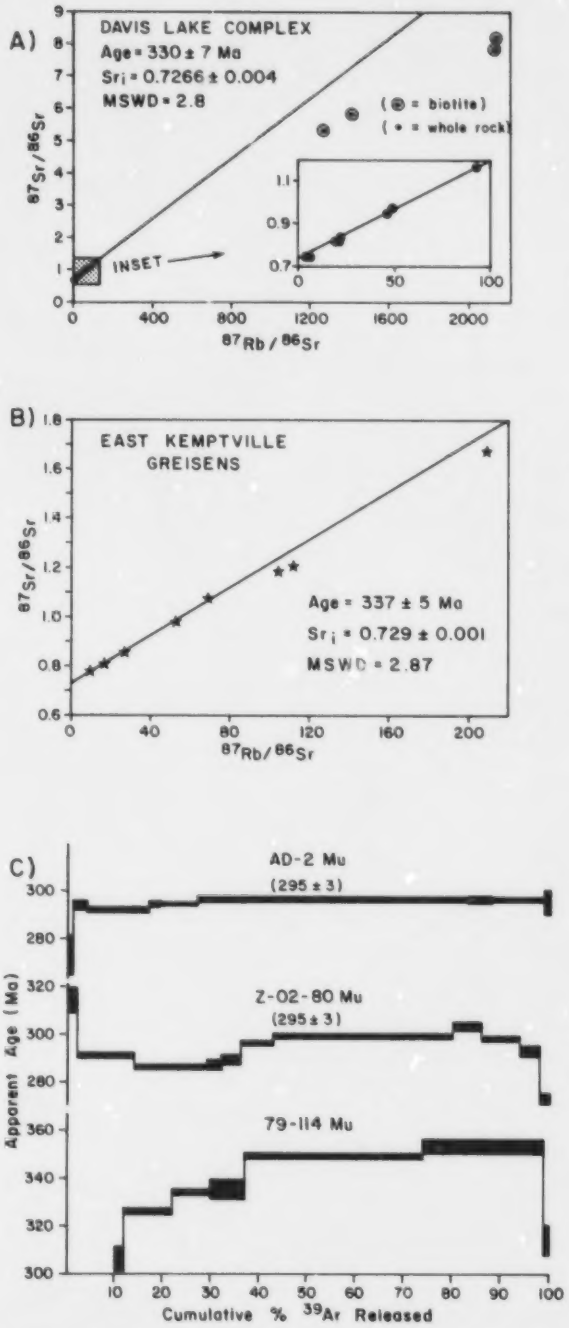

Figure 2. Summary of previously published geochronological data for the EKL and DLP. (a) Whole rock Rb/Sr isochron diagram for the DLP (from Richardson, 1988b). The open circles represent biotite separates. Note that the age reported (i.e. 330 ± 7 Ma) is for 5 samples from the interior of the DLP and 3 of the whole rock samples shown on the diagram are omitted from the age calculation (see Richardson (1988b) for discussion). (b) Rb/Sr isochron diagram for greisen samples from the East Kemptville tin deposit (from Richardson et al., 1988b). The regressed line and age do not include the 3 points with elevated Rb/Sr ratios. (c) Apparent age spectra for muscovites analyzed by Zentilli and Reynolds (1985). Note that the low temperature gas release in samples Z-02-80 and 79-114 record overprinting events of <300 Ma age.

in Faure (1977). All data are reported at the 2 sigma confidence level and isotopic abundances and decay constants used are those recommended in Steiger and Jager (1977).

ANALYTICAL RESULTS

Results for the whole rock Rb/Sr and muscovite $^{40}Ar/^{39}Ar$ analyses are presented in Figure 3, while a summary of all the preliminary age data for the different subsets of Rb/Sr data (whole rock, mineral concentrates) is given in Table 1. A more detailed treatment of the data and additional analyses will be presented elsewhere. As additional analyses are still in progress, we note that some of the ages reported here are likely to change, hence, the ages presented should be considered as tentative.

$^{40}Ar/^{39}Ar$ Data

The age spectrum for the muscovite sample (Fig. 3a) is clearly discordant with the initial 32% of the gas released indicating a complex pattern resembling a quasi-diffusion profile. The low temperature steps define an apparent age of ca. 270-280 Ma which may have some significance in terms of the timing of an overprinting event (see below). The higher temperature fractions (870 to 950 °C) account for 66% of the gas released and define a good plateau with an apparent age of 337 ± 4 Ma. The total gas age for this sample is 326 Ma.

Rb/Sr Data

Results of the 10 whole rock analyses (Fig. 3b) indicate an excellent isochron with an age of 355 ± 5 Ma, initial $^{87}Sr/^{86}Sr$ ratio (Sr_i) of 0.7252 ± 0.0058 and Mean Squares Weighted Deviates value (MSWD) of 1.53 (F-value = 2.77). The four whole rock samples minus their muscovite fractions indicate a slightly older age of 372 ± 8 Ma with a lower Sr_i of 0.7201 ± 0.0178. Four 3-point isochron ages defined by muscovite-quartz/feldspar-whole rock samples yield ages ranging from 372 Ma to 324 Ma. The oldest of these ages is for sample EK-86-132 which is the freshest and least deformed specimen of EKL for which data are available, consequently it is considered to provide the most reliable age (372 Ma) and Sr_i (0.7187). The four muscovite

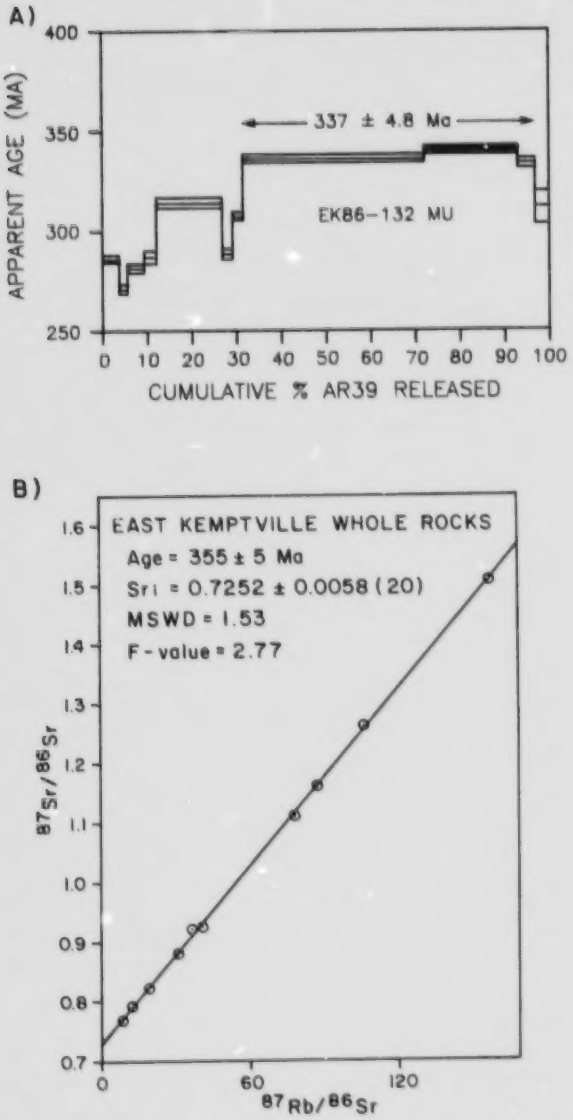

Figure 3. (a) Apparent age spectrum diagram for sample EK-86-132 muscovite from EKL. Total gas age for this sample is 326 Ma while the plateau age is indicated on the diagram. (b) Rb/Sr isochron diagram for 10 whole rock samples of EKL.

separates indicate an isochron age of 328 ± 5 Ma; 3-point isochrons for three samples based upon whole rock minus their muscovite fraction-alkali feldspar-quartz/plagioclase are 256, 261 and 270 Ma.

DISCUSSION

Results of the present investigation provide important constraints on the age of the EKL and subsequent tectono-thermal events. Based on these new data and results of previously published information we present the following synthesis of the chronology of events for the EKL and immediate environment.

Table 1. Summary of Rb-Sr age data for East Kemptville leucogranite.

Suite	Age (Ma)	$(^{87}Sr/^{86}Sr)_i$	N
whole rocks	355 ± 5	0.7252 ± 0.0058	10
muscovites	328 ± 5	0.7644 ± 0.0218	4
whole rock minus muscovite	372 ± 8	0.7201 ± 0.0178	4
muscovite-wrmms-whole rock:			
EK-86-132	372	0.718	3
EK-86-1075B	360	0.715	3
EK-86-023C	338	0.743	3
EK-86-161	324	0.790	3
QP-wrmms-Kf:			
EK-86-1075B	270	0.785	3
EK-86-023C	256	0.775	3
EK-86-261	261	0.887	3

Abbreviations: wrmms = whole rock minus muscovite fraction; QP = quartz-plagioclase concentrate; Kf = alkali feldspar concentrate; N = number of samples used in regression for isochron calculation; $(^{87}Sr/^{86}Sr)_i$ = initial Sr isotopic ratio.

(1) The time of intrusion and crystallization of the EKL is considered to be ca. 372 Ma with an Sr_i for the EKL of 0.7187, as determined from the whole rock-mineral concentrates for sample EK-86-132. Similar data for sample EK-86-1075B define an age of 360 Ma, slightly younger than that for EK-86-132, and Sr_i of 0.715. The apparent age of 356 ± 5 Ma defined by the 10 whole rock samples, although statistically a good isochron, has no geological significance. The young apparent age reflects redistribution of radiogenic Sr (i.e. loss of Sr in muscovite) and, hence, rotation of the data points due to an increase in the Rb/Sr ratio of the whole rock samples. This is corroborated by the 372 ± 8 Ma age determined by the four samples of whole rock analyzed after removal of their muscovite fraction.

Although we have not dated mineralized material we infer that the age of mineralization at East Kemptville is probably similar to the age of the intrusion (i.e. ca. 370 Ma). Our reasoning for this is related to the well established temporal relationship between highly evolved intrusions and mineralized centres which has been amply demonstrated in relatively simple geological

settings (e.g. Kontak et al., 1988; Snee et al., 1988).

(2) The 328 ± 5 Ma age obtained for the four muscovite separates and the 324 Ma (sample EK-86-161) and 338 Ma (sample EK-86-023C) ages determined on whole rock-mineral concentrates are interpreted to indicate the time of a major tectono-thermal event within the vicinity of the EKL. These ages are similar to the plateau age of 337 ± 4 Ma determined from $^{40}Ar/^{39}Ar$ analysis of the muscovite separate reported above and the whole rock Rb/Sr age of 337 ± 5 Ma for the East Kemptville greisens reported by Richardson et al. (1988b). It should be noted that the latter is really the same as analyzing muscovite concentrates since the greisens are quartz-topaz-muscovite rocks and Rb and Sr are wholly contained within the muscovite fraction of the rock. The similarity of this ca. 330 Ma age to (i) the 330 ± 7 Ma Rb/Sr whole rock age obtained by Richardson (1988b) and Richardson et al. (1987, 1988a) for the DLP and (ii) the high temperature gas fraction of a $^{40}Ar/^{39}Ar$ age spectrum for muscovite from the Kempt Snare Lake greisenized granite which lies within the EKSZ (Soehl et al., 1989) indicates the regional significance of this tectono-thermal event.

(3) The plateau age of ca. 295 Ma reported for two muscovite separates from greisens at East Kemptville by Zentilli and Reynolds (1985) reflect the influence of a tectono-thermal event with attendant temperatures of at least 350°C (i.e. the closure temperature of muscovite). This event may have affected the muscovite from sample EK-86-132 but, if so, a subsequent event(s) removed any evidence of this. However, this ca. 295 Ma event was obviously not pervasive enough to reset the Rb/Sr and Ar-Ar systems in the samples analyzed in this study. We also note that a second separate of greisen muscovite from Kempt Snare Lake analyzed by Soehl et al. (1989) indicated an age of ca. 300 Ma for the high temperature fraction, suggesting a regional extent for this second tectono-thermal event.

(4) The youngest event recorded is reflected by the 3-point isochrons defined by whole rock minus muscovite-alkali feldspar-quartz/plagioclase. The three samples analyzed define ages of 256 Ma, 261 Ma and 270 Ma; the range may reflect diachronous cooling or variable amounts of interaction of the rocks with fluids probably at moderately low temperatures. These ages are similar to (i) the four whole rock-biotite ages (236, 245, 252, 257 Ma) Richardson (1988b) reported for the DLP and (ii) a $^{40}Ar/^{39}Ar$ age spectrum for alkali feldspar from the Kempt Snare Lake greisenized granite (Soehl et al., 1989). Thus, the aforementioned data again indicate the pervasive nature of this event, albeit of only moderate temperature in this area. On a more regional scale we note that this age is similar to an overprinting thermal event of ca. 257 ± 8 Ma age which affected the Wedgeport Pluton some 45 km southwest of East Kemptville (Cormier et al., 1988).

CONCLUSIONS

Results of detailed Rb/Sr and $^{40}Ar/^{39}Ar$ analyses of the EKL have resolved the age of the host leucogranite and more clearly defined the presence of several tectono-thermal events. Our results indicate that the EKL, and presumably the associated mineralization, was emplaced at ca. 370 Ma, essentially coincident with intrusion of the rest of the SMB. Previous interpretations suggesting ages of ca. 330 Ma and ca. 300 Ma for the age of emplacement and mineralization at East Kemptville are considered incorrect in light of the new data presented herein. Instead, the latter ages reflect the subsequent effects of variably pervasive tectono-thermal events at ca. 330 Ma, 300 Ma and 250 Ma. More work is required in order to distinguish whether the latter events represent essentially continued, progressive deformation or discrete, separate pulses of tectonic activity.

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$^{40}AR/^{39}AR$ GEOCHRONOLOGICAL STUDIES OF MEGUMA GOLD DEPOSITS, MEGUMA TERRANE, NOVA SCOTIA[1]

D. J. Kontak, P. K. Smith, P. H. Reynolds[2] and K. Taylor[2]

INTRODUCTION

The absolute age of mineralization in an ore deposit has important ramifications for the genetic model invoked to account for the ore-forming event(s). The numerous genetic models that have been proposed for Meguma gold deposits (e.g. Keppie, 1976; McBride, 1978; Graves and Zentilli, 1982; Henderson and Henderson, 1986; Hy, 1987; Mawer, 1985, 1986, 1987; Haynes, 1986, 1987) all suffer from the absence of data regarding the absolute timing of mineralization. In an attempt to resolve this problem we have embarked on a geochronological investigation of Meguma Group gold deposits (Kontak et al., 1988b, 1989, ms under review) and in this report present the results for recently obtained $^{40}Ar/^{39}Ar$ data collected during the past year.

In a previous communication (Kontak et al., 1988b) preliminary $^{40}Ar/^{39}Ar$ ages for hydrothermal muscovite and biotite from mineralized veins at the Beaver Dam deposit area were presented and their implications for gold mineralization discussed. The inferred age for mineralization of ca. 370 Ma, although much younger than most models for Meguma gold deposits would generally have predicted (e.g. Graves and Zentilli, 1982; Henderson and Henderson, 1986; Keppie, 1976), was interpreted to be consistent with the geological setting of the gold deposit. Additional data have been obtained for hydrothermal biotites and a single hydrothermal amphibole sample collected from within the Beaver Dam deposit and also for mica separates from the nearby (ca. 2 km) River Lake Pluton. In addition, mica separates from the Caribou, Fifteen Mile Stream and Upper Seal Harbour deposit areas have been analyzed using the $^{40}Ar/^{39}Ar$ technique. We summarize herein only the salient aspects of the samples and analytical data. A detailed discussion of the geology of the individual deposits, samples analyzed, and interpretation of the analytical data is beyond the scope of this paper and will be presented elsewhere (e.g. Kontak et al., ms under review).

SAMPLE DESCRIPTIONS

Beaver Dam Deposit Area

A sample of fresh, coarse grained, two-mica granite from the River Lake Pluton was collected from along provincial highway 224 approximately 1.5 km north of the turn-off for Beaver Dam. The muscovite and biotite separated (RL-86-1 ms, bt) from this sample are free of secondary alteration and no signs of deformational features (e.g. kinking, pressure bands) were observed during thin section examination. Three new samples from the Beaver Dam deposit itself were collected: sample BD-87-136 from a large fissure vein along the 140E drift on the 1080 level, sample BD-87-177 from a large fissure vein along the 21 drift on the 1040 level and sample BD-87-61A from a bedding parallel vein in the Papke Zone on the 1100 level (near the bulkhead). In the first two samples the biotite occurs as part of silicate clots in the quartz veins along with Ca-rich plagioclase, tourmaline, muscovite, carbonate, chlorite and sulphides ± apatite. Biotite separates from these samples are free of alteration and deformational textures, and are considered to represent early stage hypogene mineralization (see Kontak and Smith (1988) for discussion of mineral paragenesis at this locality). The amphibole-bearing sample, also representative of early stage mineralization, occurs as a silicate-rich vein of 20 cm width with abundant (i.e. 60 modal %) actinolitic hornblende coexisting with biotite, Ca-rich plagioclase ± carbonate ± chlorite ± sulphides. The amphibole is free of both low temperature alteration and deformational textures.

Fifteen Mile Stream Deposit

A single sample of biotite was collected from this deposit area during reconnaissance field work

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement
2 Department of Geology, Dalhousie University, Halifax, Nova Scotia B3H 3J5

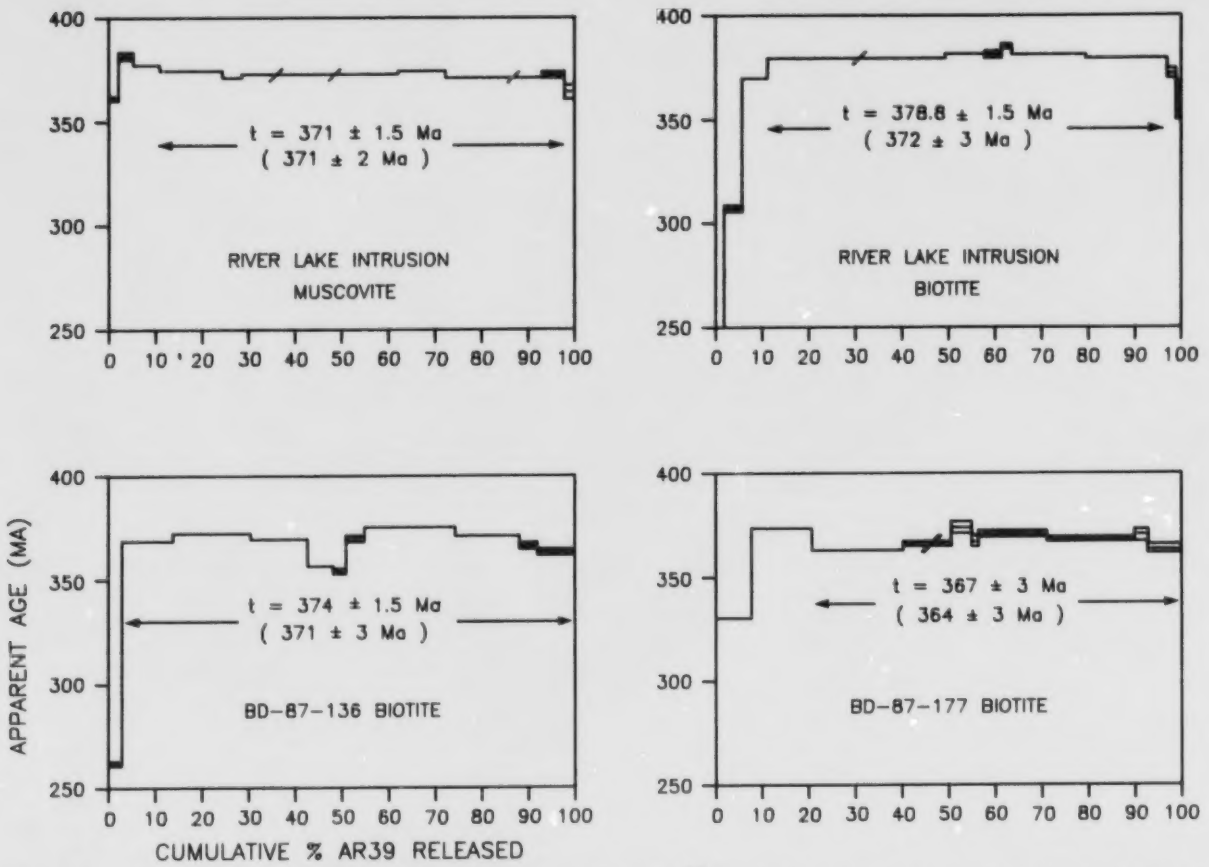

Figure 1. Age spectra plots (apparent age versus cumulative % ^{39}Ar) for biotite (bt) and muscovite (mu) mineral separates from the River Lake intrusion and Beaver Dam gold deposit (BD-86-136, BD-87-177). The apparent plateau ages are indicated for each sample along with the total gas or integrated age in parentheses.

during 1986. Sample FMS-86-3, collected from dump rock material in the vicinity of the old New Egerton workings, consists of a fine grained, monomineralic clot of dark brown biotite in wall rock pelite adjacent to a bedding-parallel quartz vein with crack-seal texture. Because of the proximity of the biotite clot to the quartz vein we consider it probable that the biotite represents an alteration selvage to the vein and, therefore, formed essentially contemporaneously with the vein.

Caribou Deposit

Two samples were collected from this deposit during underground mapping of old and new workings during the fall of 1988. Sample CAR-88-50 comes from a discordant vein in the 558 crosscut on the 500 foot level. The majority of the vein consists of milky white quartz with coarse carbonate and large arsenopyrite crystals. The sample for dating represents a carbonate-chlorite-muscovite clot from along the vein margin. The second sample, CAR-88-23, was collected from the 800 foot level, midway between the Main Zone and the A Zone on this level, and represents stockwork mineralization. The vein assemblage at this locality consists of quartz-carbonate-chlorite-muscovite with ore-grade gold assays.

Upper Seal Harbour Deposit

A single sample from this locality was collected during the winter of 1989 from new underground workings. The sample, USH-89-3, comes from a zone of massive, en echelon stockwork veins (total width 17 m) on the 250 foot level approximately 30 m north of the main fold hinge. The mineral assemblage in the vein consists of quartz-carbonate-chlorite-feldspar-muscovite.

METHODS

All minerals dated represent >99% pure separates

that were prepared using conventional mineral separating techniques (i.e. a Frantz isodynamic separator and heavy liquids). Details of the $^{40}Ar/^{39}Ar$ analytical procedures employed at the Dalhousie geochron laboratory are provided in Reynolds et al. (1987) and a full set of the data is available upon request from the senior author. The isotopic abundances and decay constants used are those recommended by Steiger and Jaeger (1977) and all errors are calculated at the 2 sigma level. An age plateau is as defined in Fleck et al. (1977).

ANALYTICAL RESULTS

Beaver Dam Deposit

Micas from the River Lake Pluton give simple age spectra with apparent plateau ages of ca. 371 Ma and 379 Ma for muscovite and biotite, respectively (Fig. 1). The integrated, or total apparent gas ages, for the same samples are 371 ± 4 Ma and 372 ± 4 Ma, respectively. The apparent reverse discordance in the ages (i.e. biotite older than coexisting muscovite) is anomalous for Meguma Terrane granites when compared to previously published data (Reynolds et al., 1981, 1987; Keppie and Dallmeyer, 1987) but not unique to this intrusion (e.g. see Table 1 of Reynolds et al., 1981). The muscovite age is considered the most reliable and, therefore, we take ca. 371 Ma to be the age of this intrusion. This age is similar to a plateau age of ca. 371 Ma for muscovite from a pegmatite/aplite sample reported in Kontak et al. (1988b) from just north of the River Lake intrusion.

The data obtained for BD-87-61A amphibole are complicated by the fact that there was a small leak in the quartz tube furnace during the analysis. Although the data have been corrected for this problem (as discussed in Kontak et al., ms under review), we note that the apparently large errors in the age spectrum plot relate to this problem. However, the age spectrum (Fig. 2b) indicates a simple thermal history for this sample and the apparent K/Ca ratios (Fig. 2a) indicate that the gas was released from a chemically homogeneous phase, consistent with optical observations. We also show a $^{40}Ar/^{36}Ar$-$^{39}Ar/^{36}Ar$ isotope correlation diagram (Fig. 2c) for these data which when regressed (method of York, 1969) suggest an apparent age of 367 ± 10 Ma, not significantly different from the rather poorly defined plateau age (ca. 365 Ma) indicated in Fig. 2b or the total gas age of 361 ± 16 Ma.

The two biotite separates from within the deposit indicate apparent plateau ages of ca. 367

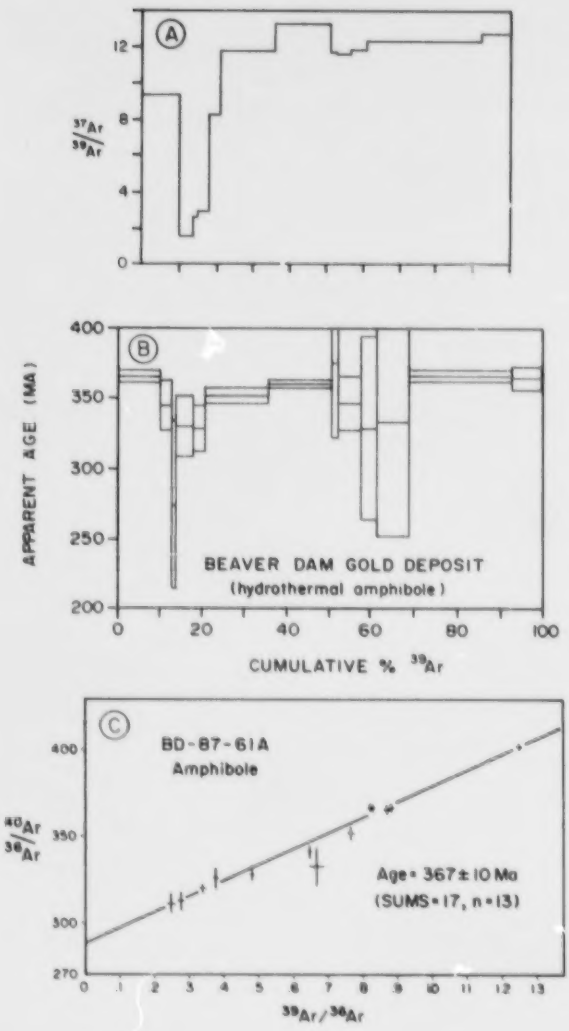

Figure 2. Age data for sample BD-87-61A amphibole from the Beaver Dam deposit. (a) Plot of $^{37}Ar/^{39}Ar$ (this is proportional to the apparent K/Ca ratio of the sample) versus cumulative I ^{39}Ar released. (b) Age spectrum plot of apparent age versus cumulative I ^{39}Ar released. Note that the unusually large errors for some of the intermediate steps are related to a combination of small gas fractions released for these temperature intervals and a leak in the quartz furnace tube during analysis of this sample. (c) $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ isotope correlation or isochron plot (i.e. slope of the line is proportional to age). Note that the scatter of the data about the best fit line is not in excess of that expected on the basis of the assigned errors (i.e. SUMS=17 for n=13) and, hence, the data define an isochron.

± 3 Ma (BD-86-177) and 374 ± 1.5 Ma (BD-87-136) and total gas ages of 364 ± 3 Ma and 371 ± 3 Ma, respectively. The age spectrum for BD-87-136 is complicated somewhat by a distinct saddle structure or depression in the intermediate part of

the age spectrum (Fig. 1). This may be an artifact of the irradiation procedure (i.e. recoil effect) related to incipient chloritization of the biotite (see Muecke et al., 1988 for a more detailed discussion). These results compare favourably with our previously published $^{40}Ar/^{39}Ar$ age data from this deposit for which ages of 376 ± 4 Ma (biotite) and 374 ± 4 Ma (muscovite) were obtained (Kontak et al., 1988b).

Fifteen Mile Stream

Sample FMS-86-3 has a total gas age of 357 ± 4 Ma and an apparent plateau age, as defined by the low to intermediate temperature steps, of ca. 363 Ma (Fig. 3). The age spectrum has a distinct saddle structure or depression, as observed in sample BD-87-136, although from a slightly higher temperature gas fraction (i.e. 900°C versus 750-800°C), and a similar explanation is offered to account for this. As with the Beaver Dam samples, a simple thermal history is suggested for this sample.

Caribou Deposit

The two muscovite separates from the Caribou deposit, samples CAR-88-23 and CAR-88-50, give apparent total gas ages of 367 ± 4 Ma and 380 ± 4 Ma, respectively. The corresponding apparent plateau ages for these samples are ca. 372 Ma and 382 Ma, respectively (Fig. 3). The saddle structure observed in sample CAR-88-23 is probably not real and is instead a reflection of either instrumental or operator error, or a combination of the two. As with the above samples, a simple thermal history is implied for these micas.

Upper Seal Harbour

Sample USH-89-3 muscovite has a total apparent gas age of 366 ± 4 Ma and a well defined plateau age of ca. 366 Ma (Fig. 3). The age spectrum for this muscovite is uniform from the low to high temperature gas fractions and indicates a simple thermal history for the sample.

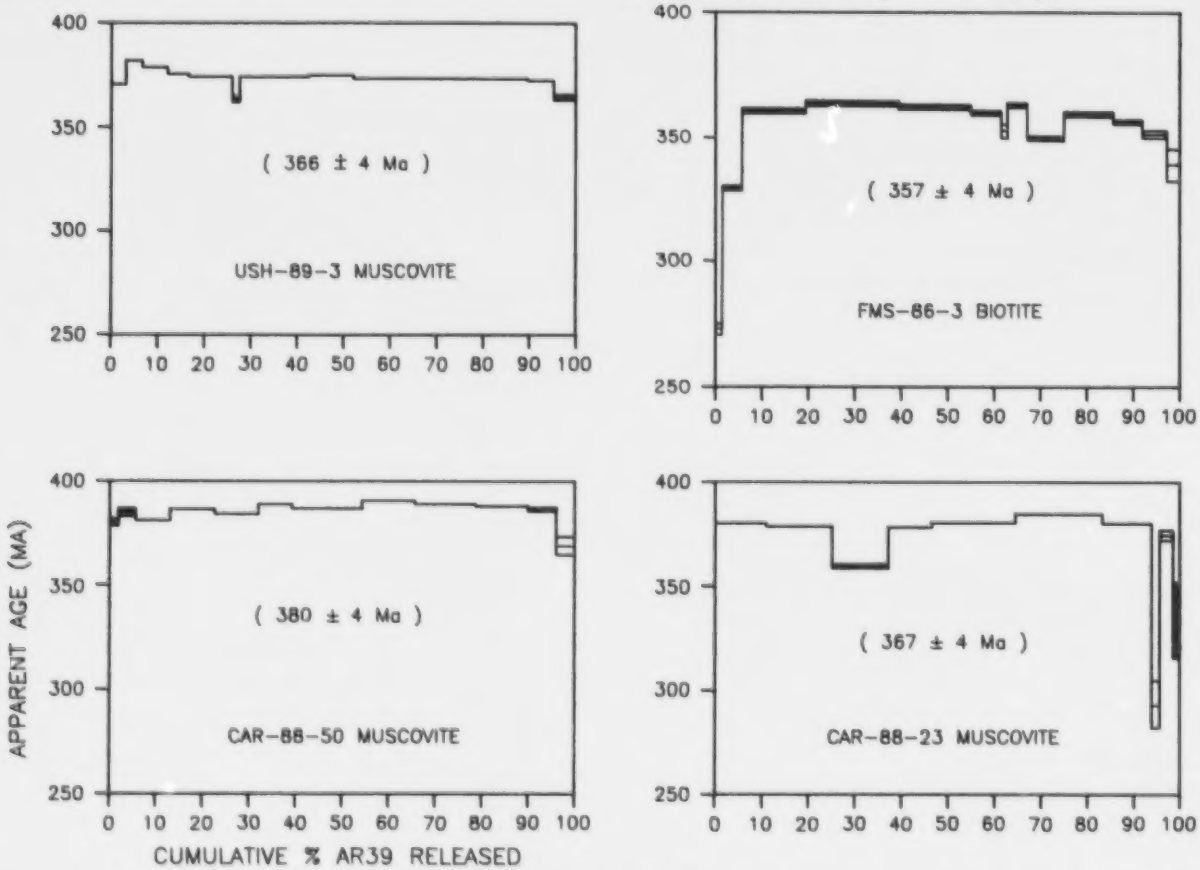

Figure 3. Age spectra plots (apparent age versus cumulative % ^{39}Ar) for biotite (bt) and muscovite (mu) mineral separates from the Upper Seal Harbor (USH), Fifteen Mile Stream (FMS) and Caribou (CAR) gold deposits. The apparent plateau age for each sample is indicated along with the total gas or integrated age in parentheses.

DISCUSSION

Results of the present investigation confirm our earlier conclusions (Kontak et al., 1988b) which were based on fewer samples from a single deposit area (i.e. Beaver Dam). The additional samples analyzed here extend our sampling to four deposit areas, but more importantly permit comparison of age data from districts over a large geographic area and for different metamorphic grades of the host rocks (Caribou is hosted by low grade metamorphic rocks while Upper Seal Harbour is hosted by high grade metamorphic rocks). Although detailed discussion of the results are beyond the scope of this paper, we draw attention to the following points.

(1) The concordance of age data for minerals (i.e. biotite, muscovite, amphibole) with highly differing blocking temperatures (i.e. >500°C to <300°C) from the Beaver Dam deposit area is interpreted to indicate that veining and, hence, probably also mineralization, occurred at ca. 370 Ma. A reheating event coincident with emplacement of the River Lake Pluton, which would have caused complete degassing of Ar in the minerals, is not considered as an alternative interpretation (see Kontak et al., ms under review for more detailed discussion).

(2) The ca. 10 Ma range in apparent ages for the two samples from the Caribou deposit may be interpreted in several ways. (i) The different ages may reflect a protracted interval for the mineralizing event or two periods of mineralization separated in time by ca. 10 Ma. (ii) The ages may indicate that the ambient temperature in at least part of the deposit area remained above the Ar blocking temperature for muscovite (approximately 350°C) for ca. 10 Ma after the mineralizing event ceased. (iii) The anomalously old age of ca. 382 Ma is erroneous and instead reflects not the age of mineralization but is related to excess argon in the sample or (iv) some unknown analytical problem. At present it is difficult to choose which of these solutions is correct and further work will have to be done to resolve this problem.

(3) Except for the anomalously old sample from the Caribou deposit, all the remaining samples from the four deposits give apparent plateau ages of ca. 363-373 Ma. In addition, all the samples have relatively flat age spectra (Figs. 1, 2, 3) which indicate simple thermal histories for all the areas. We interpret the data, therefore, as reflecting a regional, gold-forming metallogenic event at ca. 368 $\pm$ 5 Ma which was apparently coincident throughout the Meguma Terrane. It is important to note (i) that the ages obtained for this event appear to be independent of the variable metamorphic grade of the host rock lithologies (i.e. greenschist versus amphibolite facies) and (ii) that diachronous cooling did not occur.

(4) Although the timing of gold mineralization is essentially coincident with emplacement of large volumes of peraluminous granitoid rock and mafic magmatism within the Meguma Terrane at ca. 370 Ma, we do not suggest anything more than a temporal association. It is distinctly possible that the magmatism may have been related to an important thermal reservoir but a direct genetic connection is ruled out on the basis of isotopic evidence (Kontak et al., 1988a).

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GEOCHEMISTRY OF WALL ROCK AND VEIN LITHOLOGIES AT THE FOREST HILL GOLD DEPOSIT, MEGUMA TERRANE, NOVA SCOTIA: PRELIMINARY RESULTS FROM A STUDY OF THE 9+00 (METRES) EAST TRENCH[1]

P. K. Smith and D. J. Kontak

INTRODUCTION AND GEOLOGICAL SETTING

The Forest Hill gold district is located in the northeastern part of the Meguma Terrane in southern Nova Scotia adjacent to the Cobequid-Chedabucto Fault System (Fig. 1). The Forest Hill deposit, with an historical production of 25,102 ounces of gold extracted from 54,002 tons of ore milled (Bates, 1987), is hosted by metasedimentary rocks of the Lower Paleozoic Goldenville Formation and is an excellent example of quartz vein type mineralization hosted by high-grade (i.e. upper amphibolite facies) metasedimentary lithologies. Regional deformation followed by regional metamorphism are overprinted by granitic plutonism (ca. 370 Ma), fluid-related anomalous metamorphism, shear deformation and mineralization during the latter stages of the Acadian Orogeny.

Gold mineralization at Forest Hill occurs predominantly in lenticular, bedding concordant quartz ± silicate ± sulphide-rich veins in a psammite-dominant stratigraphy with lesser amounts of interbedded pelite, semipelite and calc-silicate. In some parts of the underground workings moderately deformed granitic pegmatite dykes crosscut strongly deformed auriferous quartz veins. Where vein and pegmatite intersect, gold is present in both. The mineralization is located on the steeply dipping southern limb of the Forest Hill anticline (Fig. 1; Smith et al., 1985). The area has undergone polyphase deformation, as indicated by superimposed fabrics and different generations of folds. Similar deformation has been described on a regional scale by Mawer and Williams (1986) and Hill (1987). The high-grade metamorphism occurred synchronously with shear deformation of the veins and wall rocks in this area.

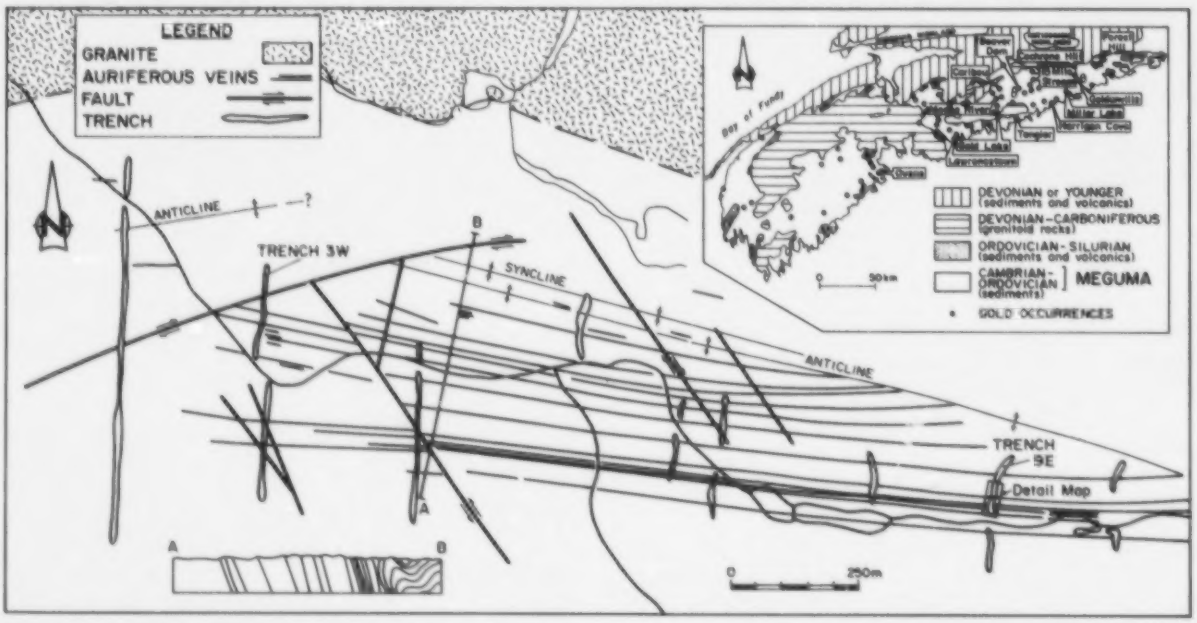
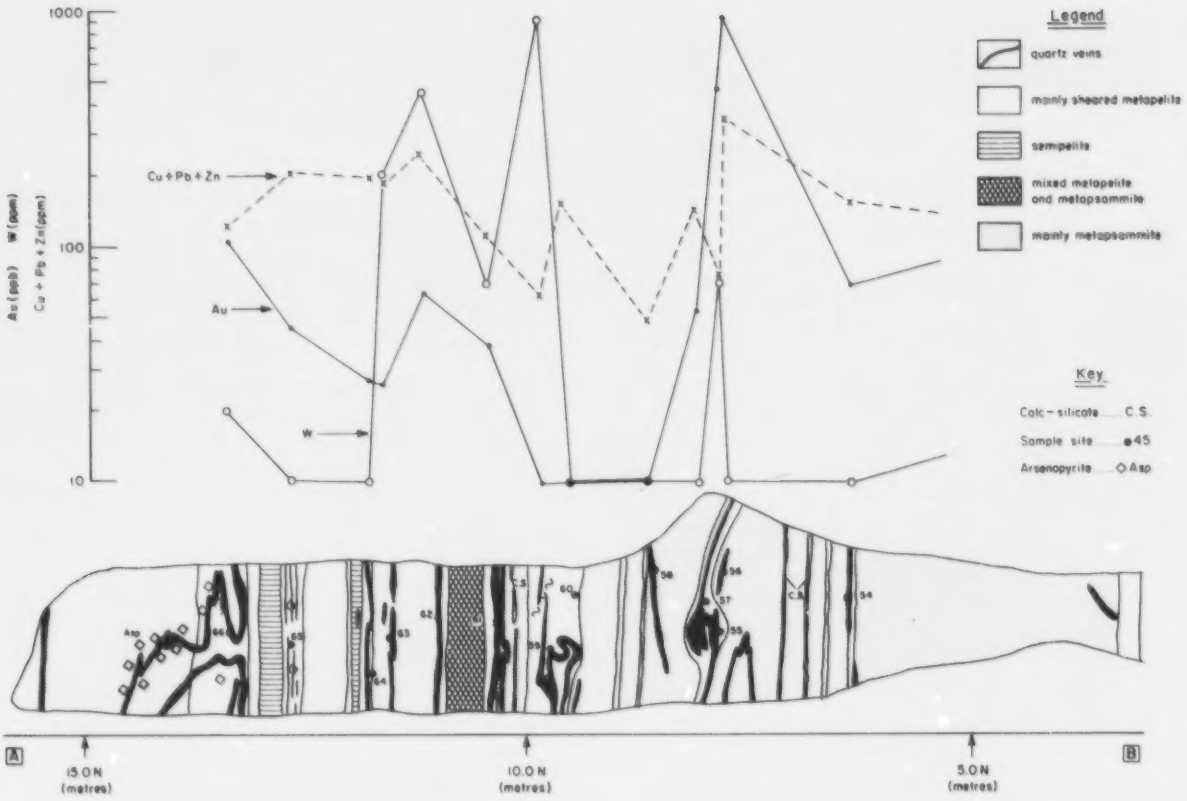
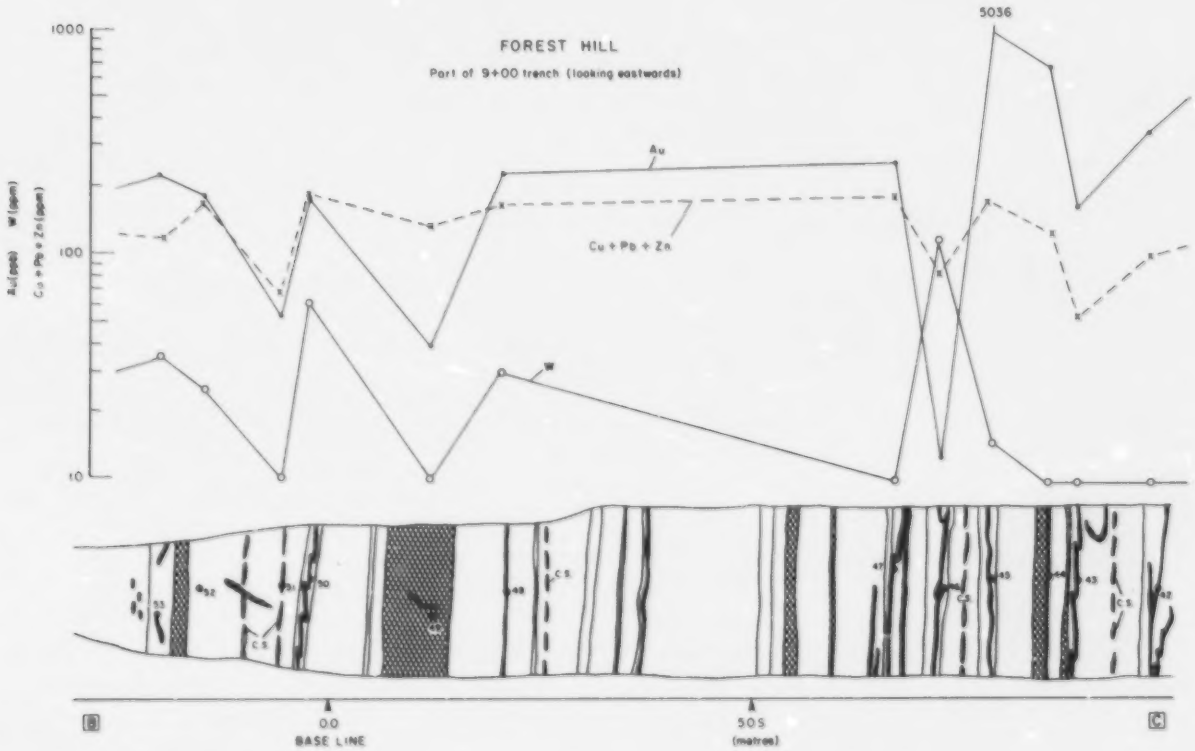


Figure 1. Location map of the Forest Hill gold district in the eastern part of the Meguma Terrane. Detailed geology map of the Forest Hill deposit (modified after Faribault, 1935) shows the location of trench 9+00 east. Inset map of cross-section A-B shows fold pattern of major quartz leads.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

NSDME Report 89-3


1000
100
10
Au (ppb) W (ppm)
Cu + Pb + Zn (ppm)
Cu+Pb+Zn
Au
W
Legend
quartz veins
mainly sheared metapelite
semipelite
mixed metapelite and metapsammite
mainly metapsammite
Key
Calc – silicate ..... C.S.
Sample site ..... ●45
Arsenopyrite ..... ◇Asp
A
B
15.0 N (metres)
10.0 N (metres)
5.0 N (metres)


FOREST HILL
Part of 9+00 trench (looking eastwards)
1000
100
10
Au (ppb) W (ppm)
Cu + Pb + Zn (ppm)
5036
Au
Cu + Pb + Zn
W
B
C
0.0 BASE LINE
5.0 S (metres)

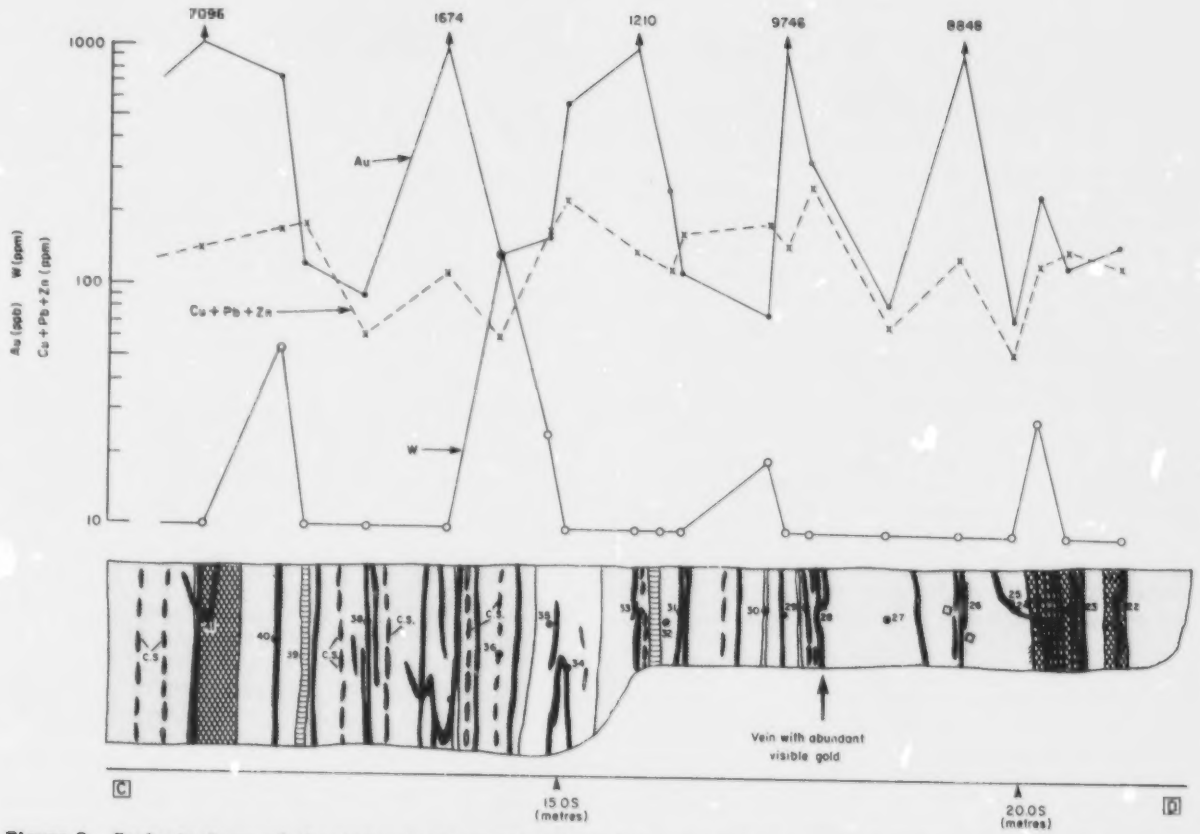


Figure 2. Geological map of the east wall of trench 9+00 east showing geology, sample locations and elemental profiles for Au (ppb), W (ppm) and Cu-Pb-Zn (ppm).

This paper documents some of the results obtained from mapping and sampling of a surface trench at section 9+00 (metres) east prior to underground development.

LOCAL GEOLOGY

Stratigraphy of Trench 9+00 East

For this study 38 m of trench section 9+00 east were mapped and selectively sampled to examine in detail the general petrographic and geochemical features of the strata. A face map for part of the trench (Fig. 2) shows that psammitic lithologies dominate the stratigraphy. These rocks show pervasive metamorphic recrystallization with biotite and garnet dominating the modal mineralogy and lesser amounts of quartz, plagioclase, muscovite, chlorite (retrograde), opaques and accessories. Regional cleavage is not well developed in these rocks, but a post-metamorphic shear cleavage is present.

Semipelites contain coarse (1 mm - 1 cm) porphyroblasts of staurolite, cordierte, garnet and biotite, with finer grained but equally abundant quartz, plagioclase and chlorite in the groundmass. All the porphyroblasts show deformation and rotation related to the shear cleavage.

The mineralogy of the interbedded pelites is dominated by sericite and biotite with subordinate amounts of quartz, chlorite, sulphides (pyrite, pyrrhotite, arsenopyrite) and opaques. Biotite porphyroblasts are invariably rotated by the shear fabric. Tourmaline alteration within the pelites is common adjacent to quartz veins.

Quartz Veins

Quartz veins at Forest Hill may be broadly categorized as either concordant or discordant depending on their geometrical relationship with bedding in the enveloping wall rock lithologies. It is noted that because of the high degree of strain in these rocks that some original discordant veins have been rotated into near alignment with bedding and presently appear as concordant veins. Concordant veins occur preferentially in pelites or along psammite/pelite contacts. Tight upright

folds and boudinage are common. Where strain is most pronounced the veins may be dismembered and strung out as individual lozenge-shaped segments of about 1-2 m length. Although quartz is consistently the most dominant vein constituent, locally other gangue minerals, including Ca-rich plagioclase, biotite, andalusite, muscovite, actinolite, garnet, calcite, siderite, dolomite, tourmaline and chlorite, may be variably abundant giving the veins a pegmatitic appearance, thus leading to the term pegmatoid veins (Smith, 1983). Dominant ore minerals include native gold (containing 2-10 wt. % Ag), arsenopyrite, pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, ilmenite, rutile and scheelite. Mineralogy of the discordant veins is similar to the concordant veins, although relative abundances of gangue and sulphide minerals differ. The discordant veins are generally parallel to the northeast-southwest faults which show variable displacements up to tens of metres. Late, crosscutting fractures in these veins commonly contain minor gold with calcite, pyrite and pyrrhotite.

GEOCHEMISTRY OF WALL ROCK AND VEIN SAMPLES

As part of our comprehensive investigation into Meguma gold deposits a geochemical database is being established for as many deposits as possible. Although it is difficult to discuss the results for a single deposit area in isolation, the data from Forest Hill do warrant discussion as some significant features are indicated. A more comprehensive treatment of this data will be presented elsewhere with additional analyses.

Methods

After detailed mapping, selective sampling of trench 9+00 east was carried out in order to obtain a representative suite of samples that collectively reflected the maximum variation in wall rock lithology and veins. The sample locations are shown in Figure 2 (except for specimens 1 - 21, which were collected from the west face of the trench between 9 and 15 m north of the base line). A total of 70 samples were prepared and analyzed for major and trace elements at the Technical University of Nova Scotia. Average analysis as well as the minimum and maximum range for 45 veins, 10 pelites, 6 semipelites, 7 psammites and 2 calc-silicates are presented in Table 1; individual analyses and subsequent samples for other parts of the Forest Hill deposit area will be presented in a forth-coming paper. The reader should note that the large variation in the data, for vein samples in particular, reflects the combined effects of highly variable mineralogy (see above) and the presence of wall rock inclusions.

In addition to the standard major and trace elements analyzed, some samples were also selected for analysis of their rare earth element (REE) contents. These elements are sometimes good monitors of alteration processes and, therefore, a reconnaissance study seemed appropriate. Analyses were performed at Memorial University of Newfoundland using the thin-film X-ray fluorescence technique. The raw data are not provided here, but a copy may be obtained upon request.

Major and Trace Element Chemistry

The data for Au, W and base metals (Cu + Pb + Zn) are plotted in Figure 2 so that a direct comparison can be made between this commonly associated group of elements and the geology of trench 9+00 east. We emphasize the following salient aspects of the data: (1) For most samples the Au and base metal values are clearly elevated above normal background levels both for wall rock and vein material, and although some W values are elevated there is no direct correlation with it and the base metals. (2) Although base metal values tend to remain fairly constant along the length of the trench regardless of host rock, Au values show a much more erratic, albeit parallel, distribution with them. (3) The significant but erratic enrichment of Au in the wall rock reflects movement of fluids away from the veins (i.e. alteration halos) as well as the presence of Au in sulphides. (4) Although not shown graphically, the data in Table 1 indicate that there is no consistent correlation between Au and As in these samples. This confirms what is generally observed in petrographic studies: if gold is present in arsenopyrite it generally occupies late fractures and, therefore, post-dates the host. Hence, erratic correlations reflect a fortuitous coincidence rather than a consistent genetic association.

In Figure 3a, a ternary plot of Fe_2O_3-MgO-TiO_2, data for mineralized samples from Forest Hill and unmineralized Meguma Group sediments well away from known mineralization are compared. There is a general overlap of the two data sets, but a minor depletion in TiO_2 for the Forest Hill data is apparent. Although speculative, we suggest on a petrographic basis that this may reflect suphidization of the Fe-Ti phases in the Forest Hill lithologies with concomitant loss of Ti which may have gone into the veins (i.e., biotite, rutile, ilmenite) or been transported outside of the immediate system.

Table 1. Summary of analytical results from the 9+00 m east trench, Forest Hill.

	AVERAGE QUARTZ VEIN N=45			AVERAGE PSAMMITE N=7			CALC-SILICATE N=2			AVERAGE SEMIPELITE N=6			AVERAGE PELITE N=10		
	AVERAGE	RANGE MIN.	RANGE MAX.	AVERAGE	RANGE MIN.	RANGE MAX.	FA-91-36	FA-91-51	AVERAGE	AVERAGE	RANGE MIN.	RANGE MAX.	AVERAGE	RANGE MIN.	RANGE MAX.
SiO_2	75.30	53.85	91.44	76.29	73.48	78.48	76.12	74.83	75.48	66.51	56.89	78.05	64.25	53.32	76.12
TiO_2	0.492	0.138	1.855	0.516	0.469	0.579	0.560	0.486	0.527	0.684	0.467	0.839	0.724	0.4	1.089
Al_2O_3	11.09	3.78	20.21	11.27	10.6	12.11	11.17	11.98	11.58	15.49	10.84	19.46	16.36	10.56	21.91
FeO	4.60	1.35	9.75	3.54	2.62	4.95	3.32	3.67	3.45	6.41	2.69	9.98	7.23	4.75	10.98
MnO	0.154	0.027	2.719	0.073	0.048	0.114	0.16	0.222	0.191	0.093	0.057	0.115	0.097	0.07	0.129
MgO	1.68	0.48	3.23	1.34	1.13	1.61	1.66	1.43	1.55	2.37	1.18	3.25	2.35	1.61	3.62
CaO	1.70	0.24	6.2	1.75	0.48	2.75	2.77	3.19	2.98	1.05	0.46	1.69	1.06	0.32	2.05
Na_2O	2.08	0.66	3.65	2.55	1.77	3.1	1.5	1.47	1.49	2.46	1.75	2.96	2.16	1.09	3.38
K_2O	2.64	0.7	8.13	2.54	2.22	3.28	2.64	2.51	2.58	4.78	2.28	8.02	5.35	2.61	10.03
P_2O_5	0.239	0.034	0.882	0.139	0.068	0.197	0.191	0.211	0.201	0.164	0.062	0.328	0.232	0.154	0.348
Au(ppb)	494	3	9746	1178	0	7686	140	53	97	80	5	131	123	12	357
As(ppm)	1010	7	10000	2879	4	10000	15	11	13	101	4	370	744	15	4380
Ag(ppm)	0.5	0.2	9.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ba(ppm)	467	90	1330	454	250	850	500	485	493	863	320	1790	957	385	1890
Sr(ppm)	203	37	690	192	141	250	177	260	219	165	125	210	161	62	285
Be(ppm)	1.4	0.5	4	0.6	0.5	1	0.5	0.5	0.5	1.3	0.5	2	1.5	0.5	3
Bi(ppm)	2	2	5	3	2	8	2	2	2	2	2	2	2	2	2
Mo(ppm)	2	1	13	1	1	2	1	1	1	3	1	7	2	1	5
W (ppm)	39	10	930	10	10	10	140	10	75	14	10	35	21	10	70
Co(ppm)	15	4	39	13	10	20	10	12	11	23	9	36	27	16	51
Cr(ppm)	84	28	160	71	44	110	43	98	71	103	55	160	113	86	150
Ni(ppm)	26	8	57	20	15	24	15	22	19	36	16	53	40	28	61
Cu(ppm)	43	4	265	19	14	24	16	20	18	39	12	64	45	27	57
Pb(ppm)	15	2	52	9	6	20	2	8	5	10	4	16	15	6	36
Zn(ppm)	77	20	170	62	50	77	44	41	43	89	46	136	113	53	173
Cd(ppm)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
V (ppm)	54	16	137	49	38	70	44	65	55	84	37	138	93	57	144

A ternary plot of CaO-K_2O-Na_2O in Figure 3b serves to illustrate several points. (1) The veins are highly irregular in their chemistry, which primarily reflects the variation in the amount of plagioclase and biotite (i.e. main variation is due to K and Ca with a more constant Na content). (2) The pelites show a pronounced trend towards the K_2O apex which may reflect increasing effects of alteration (i.e. secondary sericite; see elevated K_2O values, up to 10 wt. % in Table 1). (3) Compared to different average shale compositions (e.g. Turekian and Wedepohl, 1961; Vince and Tourtelot, 1970) the pelites from Forest Hill are anomalous in their chemistry; it is not clear whether this is a primary or secondary feature even in the apparently freshest samples. (4) The suite of wall rock samples collectively define a continuum in chemical variation, indicating that as a group they must have behaved essentially coherently during wall rock-fluid interaction.

In many of the veins and their alteration halos apatite is an abundant phase, occurring as coarse, euhedral crystals intergrown with silicate phases. Thus, the presence of P_2O_5 may be considered as a way of monitoring the additive component(s) attending alteration. A plot of TiO_2 versus P_2O_5 in Figure 3c illustrates that some veins are indeed enriched in phosphorous, whereas the majority have values more typical of the enveloping host rock. Whether phosphorous enrichment in the veins reflects local scavenging from immediate wall rocks or is due to elemental enrichment in the fluids remains uncertain. However, we note that enrichment of this element is a consistent feature of many gold camps.

Rare Earth Element Chemistry

Results of REE analyses are presented as chondrite-normalized plots grouped according to lithology in Figure 4. The following generalizations can be made with regard to the data. (1) The sedimentary lithologies (Figs. 4a and 4b) have typical shale patterns and there is little difference between data for pelites and psammites. (2) The REE patterns for wall rock lithologies are identical to those for similar lithologies outside of mineralized zones (unpublished data of Kontak) indicating, therefore, that there has been little modification due to wall rock-fluid interaction. (3) The calc-silicate sample is enriched in relative abundance over the aforementioned samples, but has an identical pattern. Additional analyses of calc-silicate units confirm this difference, but we are unable to offer an explanation for this REE behaviour. (4) Despite the presence of intense deformation in the pelite and enrichment of Au and As in some of the metasediments, there appears to have been no alteration of the typical REE patterns. (5) Patterns for the veins show a range of over 10 times chondritic abundance, but the patterns stay relatively constant except for variable Eu anomalies (i.e. positive or negative). The major element chemistry of the veins indicates that the variation in REE mainly reflects changing proportions of plagioclase and mica in the veins, hence there is a good correlation between [total REE] and [FeO+Al_2O_3+CaO+K_2O+Na_2O] (see Table 1). For example, sample 050 has the greatest +Eu anomaly and also the greatest enrichment in CaO at 6 wt. %. In contrast, sample 058 has the lowest total REE abundance and highest silica content (91

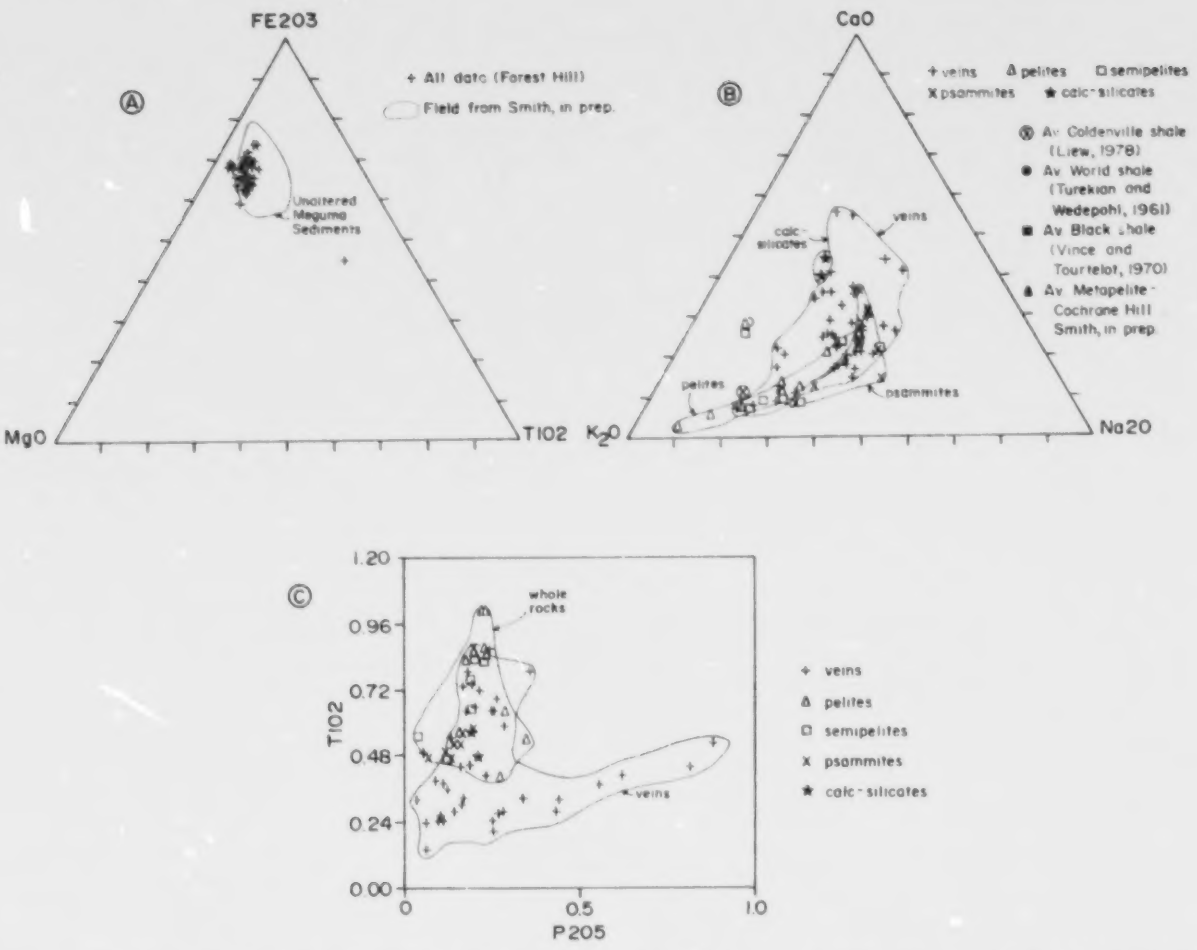


Figure 3. Lithogeochemical data for rocks from the 9+00 east trench at Forest Hill. (a) Ternary plot of Fe_2O_3-MgO-TiO_2 comparing data for Forest Hill samples to field for unmineralized Meguma Group metasediments (data from Smith, 1984). Note that the Forest Hill data are relatively depleted in TiO_2. (b) Ternary plot of CaO-K_2O-Na_2O for different lithologies from Forest Hill compared to compositions for shales from the Meguma Group (Liew, 1978; Cochrane Hill data is unpublished information of Smith) and different world average shale compositions. (c) Binary plot of P_2O_5 versus TiO_2 for different lithologies.

wt. % SiO_2) for veins analyzed for REE; hence, the quartz in this vein sample acts as a dilutant with respect to REE. However, of the remaining oxides, CaO and Al_2O_3 dominate indicating the presence of Ca-rich plagioclase which accounts for the +Eu anomaly in this sample.

Although the source of fluids responsible for the veins remains speculative, the REE data would be consistent with local derivation of components from the immediate wall rocks. Conversely, the REE data may indicate that the fluids had equilibrated with a source reservoir with similar bulk composition and mineralogy as the rocks at Forest Hill. In this latter case, either a sedimentary or igneous protolith could satisfy the chemical constraints.

MINERAL CHEMISTRY AND GEOTHERMOMETRY

Mineral chemistries of plagioclase, biotite and garnet in vein and wall rock lithologies were obtained at Dalhousie University using a Cambridge Microscan 5 electron microprobe using a 149 eV Ortec energy-dispersion system and the EDATAI data-reduction program.

Plagioclase compositions (Table 2) in wall rock pelite average $An_{23}Ab_{76}Or_1$ with no detectable difference between core and rim analyses. This composition is consistent with the metamorphic index minerals indicating amphibolite facies metamorphism for the Forest Hill area. Analysis of vein plagioclase indicates a slightly more calcic

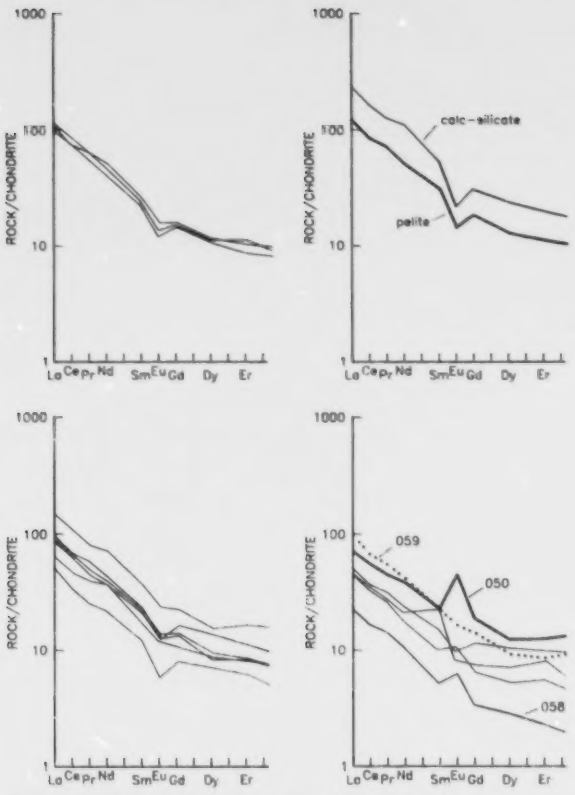


Figure 4. Chondrite-normalized rare earth element plots for different lithologies from the 9+00 trench area at Forest Hill. (a) Psammites, (b) pelite and calc-silicate units, (c) and (d) quartz veins.

composition with a mean of $An_{28}Ab_{71}Or_1$. This variation may reflect the higher activity of Ca in the fluid during vein formation.

Poikiloblastic biotite samples containing numerous zircon and opaque inclusions were analyzed from a sample of unmineralized wall rock pelite. The biotite analyses (Table 3) indicate a composition that is slightly Fe-rich with Fe/(Fe+Mg) values of 0.53 and the chemistry is typical for biotite in pelites of the amphibolite facies elsewhere within the Meguma Zone (S. Douma, personal communication, 1989).

Garnet was analyzed from the same sample as the previous biotite and the compositions (Table 4) for 4 core-rim pairs consistently indicate that the garnets are zoned from core ($Alm_{68}Spess_{18}Py_9$) to rim ($Alm_{71}Spess_{15}Py_{10}$). These garnet compositions are typical of those found in regional amphibolite facies pelites of the Meguma Group (S. Douma, personal communication, 1989).

We have used the above garnet-biotite compositions and the calibration of the temperature dependent exchange of Fe-Mg between these two minerals to calculate a temperature of metamorphism at Forest Hill. The calculated temperatures average about 520°C (errors are about ± 50°C) and there is no significant difference between values for core and rim analyses of garnet. This temperature is comparable to what Douma (personal communication, 1989) has obtained for the amphibolite facies using the same geothermometer for rocks of similar bulk composition in the eastern Meguma Terrane.

CONCLUSIONS

The important findings for this preliminary study of lithogeochemistry over part of the Forest Hill deposit area are summarized below. (1) Enrichment of gold occurs in both vein and wall rock lithologies, but the enrichment in the latter is debatable (i.e. predating or synchronous with vein formation). (2) The association of base metals (Cu, Pb, Zn) and arsenic with elevated gold values is inconsistent and cannot be used as a reliable indicator of auriferous mineralization. (3) Gold appears to be enriched several times more than base metals over their average crustal abundance. Whether this is a reflection of concentrating processes or initial contents in the mineralizing fluids remains unknown. (4) The chemistry of the veins is highly variable and is predominantly controlled by the presence of variable proportions of plagioclase and biotite, with lesser amounts of apatite and other silicates. (5) REE data for wall rock and vein lithologies give typical shale patterns, although the latter show a greater range (i.e. 10 times chondritic abundance) and reflect the relative proportions of quartz:biotite:plagioclase. The REE data are consistent with derivation from the immediate wall rocks or a source region similar to the wall rocks in bulk composition and mineralogy. The patterns have not been modified due to extensive fluid:wall rock interaction. (6) Mineral chemistry of the veins and wall rocks indicate that the assemblages have equilibrated with amphibolite facies metamorphic conditions.

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Table 2. Plagioclase microprobe analysis from auriferous zone at trench 900 m east, Forest Hill. The two samples were approximately 1 cm apart.

	FH - 900 - 5									FH - 900 - 10		
	1-C*	2-R**	3-R	3-C	4-R	4-C	5	6-R	7	8	9-R	9-C
SiO_2	62.74	62.43	62.45	63.03	62.68	62.09	62.75	62.71	61.95	62.19	60.66	60.10
TiO_2					0.13							
Al_2O_3	23.52	23.50	23.35	23.46	23.86	23.56	23.68	23.22	23.90	24.03	25.12	24.75
Fe_2O_3					0.07							
FeO		0.11	0.04	0.25		0.29	0.17	0.21				0.15
MnO				0.06	0.06							
MgO												
CaO	4.80	5.25	4.68	4.38	5.14	4.81	5.13	5.17	5.67	5.66	6.79	6.59
Na_2O	9.25	9.21	9.28	9.19	9.08	8.87	9.11	9.01	8.74	8.76	8.30	8.24
K_2O	0.09	0.15	0.17	0.33	0.16	0.15	0.14	0.20	0.07	0.14	0.17	0.20
Total	100.40	100.57	99.97	100.70	101.11	99.77	100.98	100.43	100.33	100.78	100.93	100.03
Or	0.5	0.8	0.9	1.8	0.9	0.8	0.8	1.1	0.4	0.8	0.9	1.1
Ab	77.3	75.4	77.5	77.7	75.5	76.3	75.7	75.1	73.3	73.1	68.2	68.6
An	22.2	23.8	21.6	20.5	23.6	22.9	23.6	23.8	26.3	26.1	20.9	30.3

Sample No: FH-900-5: Medium- to fine-grained, garnet-bearing biotite metapelite adjacent to auriferous vein exposed at trench 900 m east at Forest Hill. Approximately 1 cm from vein wall and cut parallel to vein wall.

FH-900-10: High grade auriferous vein from trench 900 m east at Forest Hill. Boudined stratabound vein.
* - core analysis ** - rim analysis

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Table 3. Microprobe analysis of biotite in medium grained staurolite - coordierite garnet bearing semipelite. Sample from unmineralized zone at Forest Hill, Trench 650 E.

	1	2	3
SiO_2	35.75	35.84	35.32
TiO_2	1.90	1.65	1.45
Al_2O_3	20.22	20.30	20.23
Cr_2O3	.06		
FeO	18.67	18.77	19.34
MnO	.07	.10	.13
MgO	9.23	9.57	9.79
K_2O	9.52	9.48	9.36
H_2O	3.97	3.98	3.96
SUM	99.39	99.70	99.58
Si	5.399	5.394	5.343
Al	2.601	2.606	2.657
Al	.997	.996	.949
Ti	.216	.187	.165
Cr	.007		
Fe	2.358	2.363	2.447
Mn	.009	.013	.017
Mg	2.077	2.147	2.207
K	1.834	1.820	1.806
H	4.000	4.000	4.000
O	24.000	24.000	24.000
Phlogopite	46.75	47.47	47.26
Annite	53.05	52.25	47.26
Mn	.20	.28	.36

Table 4. Core & rim microprobe analysis of garnet porphyroblasts from a staurolite - coordierite - garnet bearing medium grained semipelite. Sample from trench 650 E at Forest Hill.

	1-C	1-R	2-C	2-R	3-C	3-R	4-C	4-R
SiO_2	36.01	36.52	36.67	36.60	36.30	36.67	36.64	36.14
TiO_2	.08		.10				.26	
Al_2O_3	20.26	20.87	20.72	20.85	20.75	21.04	20.84	20.58
Fe_2O_3	.43	.87	.67	.58	.65	.42	.35	1.11
FeO	29.63	31.27	29.37	31.41	29.49	31.20	29.68	30.75
MnO	7.56	6.49	8.37	8.40	7.23	6.29	8.34	6.25
MgO	2.24	2.39	2.22	2.45	2.51	2.52	2.29	2.45
CaO	1.47	1.25	1.89	1.20	1.68	1.30	1.46	1.41
Sum	97.64	99.57	99.74	99.43	98.54	99.40	99.82	98.62
Si	5.986	5.957	5.971	5.970	5.963	5.964	5.954	5.952
Al	.014	.043	.029	.030	.037	.036	.046	.048
Al	3.954	3.968	3.946	3.978	3.980	3.996	3.944	3.946
Ti	.010		.012				.032	
Fe^{+3}	.054	.107	.062	.071	.080	.052	.042	.137
Fe	4.119	4.265	3.999	4.285	4.051	4.244	4.033	4.234
Mn	1.064	.897	1.154	.885	1.006	.866	1.148	.872
Mg	.555	.581	.539	.596	.615	.611	.555	.601
Ca	.262	.218	.295	.210	.296	.227	.254	.249
				COMPONENT/PROPORTION				
Andradite	1.35	2.72	2.03	1.81	2.11	.60	1.05	3.48
Spessartine	17.75	15.06	19.29	14.81	16.87	14.52	19.18	14.65
Grossular	2.97	.94	2.60	1.71	2.85	2.90	2.24	.53
Pyrope	9.26	9.75	9.01	9.98	10.31	10.24	9.27	10.10
Almadine	68.63	71.53	66.77	71.69	67.85	71.43	67.31	71.07

PRELIMINARY RESULTS OF A FLUID INCLUSION STUDY OF THE STOCKWORK ZONE VEIN MINERALIZATION, CARIBOU DEPOSIT, MEGUMA TERRANE, NOVA SCOTIA[1]

D. J. Kontak and P. K. Smith

INTRODUCTION

The Caribou gold deposit was one of the more significant centres of gold mining in the Meguma Terrane with an historical production of 91,381 oz. Au. The gold extracted from this deposit was produced from two contrasting styles of mineralization: a High Grade Zone of bedding-parallel quartz veins and the Main Zone which consists of stockwork quartz veins confined to a flexure in the southern limb of the Caribou anticline (Fig. 1). As part of a comprehensive geological investigation of this deposit, a fluid inclusion study of different quartz vein types is in progress. In this communication we briefly present the preliminary results of petrographic studies and thermometric measurements on quartz vein material from the Main Zone. The geology of the deposit is discussed by Malcolm (1929) and Bell (1948) and will be fully described in a comprehensive deposit description currently in preparation.

GEOLOGY OF THE MAIN ZONE

The Main Zone consists of a series of anastomosing quartz veins confined to a 10-15 m wide (maximum dimensions) flexure which is part of a late-stage kink structure superimposed on the southern limb of the Caribou Dome (Figs. 1 and 2). Both old and recent mine development has exposed this zone from surface to a depth of approximately 950 vertical feet (287 m); it remains open at depth. The kink zone trends at 315° and plunges 37° southwest. In Figure 2 it is evident that within the kink zone the quartz veins have an anastomosing nature and appear to occupy a conjugate set of fractures, hence they were emplaced late in the deformational history of this area. Although there are some bedding-parallel veins within this zone, they are considered to represent off-shoots of discordant (i.e. with respect to bedding) veins. The host lithology to the Main Zone is predominantly silicified greywacke with lesser amounts of sericitized argillite. The most intense alteration is confined to a zone enveloping the stockwork system.

The Main Zone comprises a mineral assemblage of highly variable amounts of milky white quartz, vermicular-like chlorite, carbonate, altered wall rock inclusions, sulphides (pyrite, pyrrhotite, galena, sphalerite, arsenopyrite, minor chalcopyrite) ± muscovite ± biotite. The wall rock inclusions are angular in shape and of local derivation (i.e. immediate wall rock) indicating that the Main Zone probably formed as a result of fluidized brittle fracturing (i.e. hydraulic brecciation) initiated during flexure development.

Gold occurs in the Main Zone in its native form as fine to coarse disseminations within quartz and sulphides. Grades are generally erratic throughout the zone with the average historical grade for mined ore approximately 0.5 oz./ton.

FLUID INCLUSION SAMPLING AND PETROGRAPHY

Samples for fluid inclusion study were collected from the Main Zone on the 800 foot and 500 foot levels of the Caribou deposit during the course of detailed underground geological investigations. The quartz is highly variable in texture from milky white to clear and transparent; the variable texture probably reflects different amounts of post-crystallization deformation and subgrain development. In general the best samples for inclusions were those containing intergrowths of quartz and vermicular chlorite where the quartz has suffered only minor amounts of post-crystallization deformation.

The types of fluid inclusions observed include (type 1) isolated inclusions or randomly oriented clusters of inclusions, (type 2) arrays of inclusions outlining healed fracture planes, and (type 3) arrays of inclusions outlining grain boundaries where subgrain development has occurred. Although the first two types are best preserved in

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

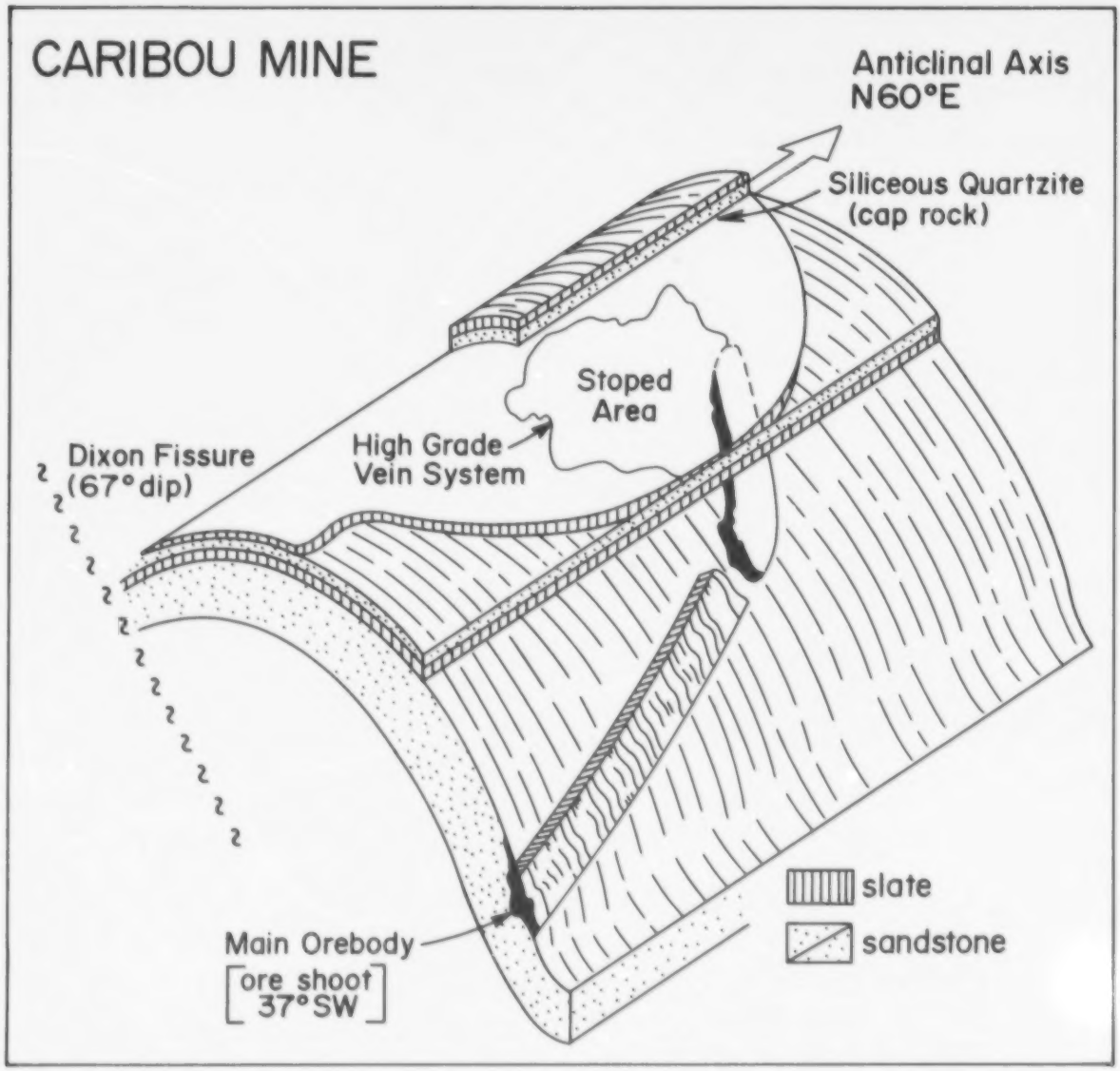

Figure 1. Schematic diagram of the Caribou Dome illustrating the nature of the two main ore zones mined at this locality. Note that recent exploration work at this property has extended the Main Zone ore shoot to surface.

least deformed quartz specimens, they are also found in the cores of subgrains of recrystallized, granular quartz. In the latter case, type 3 inclusions occur along the margins of the subgrains. Only type 1 inclusions may be considered candidates for primary inclusions, but the lack of unambiguous evidence indicative of such an origin (i.e. growth zones) suggests that these inclusions should be relegated to pseudosecondary or secondary status. However, we do note that if the criteria of Roedder (1984) are adopted then these inclusions would be considered by many people to be of primary origin.

At room temperature (25°C) types 1 and 2 inclusions generally consist of two phases: liquid H_2O and liquid CO_2; rarely the density of the CO_2 phase is such that both liquid and vapour CO_2 are observed (i.e. below its solvus). In a few cases vapour-rich, type 2 inclusions have been observed, but their scarcity makes it difficult to interpret their origin. Because of the important ramifications such inclusions might imply if interpreted as having resulted from fluid unmixing, we presently prefer to remain uncommitted as to the probable origin of these inclusions. For both types 1 and 2 the inclusions

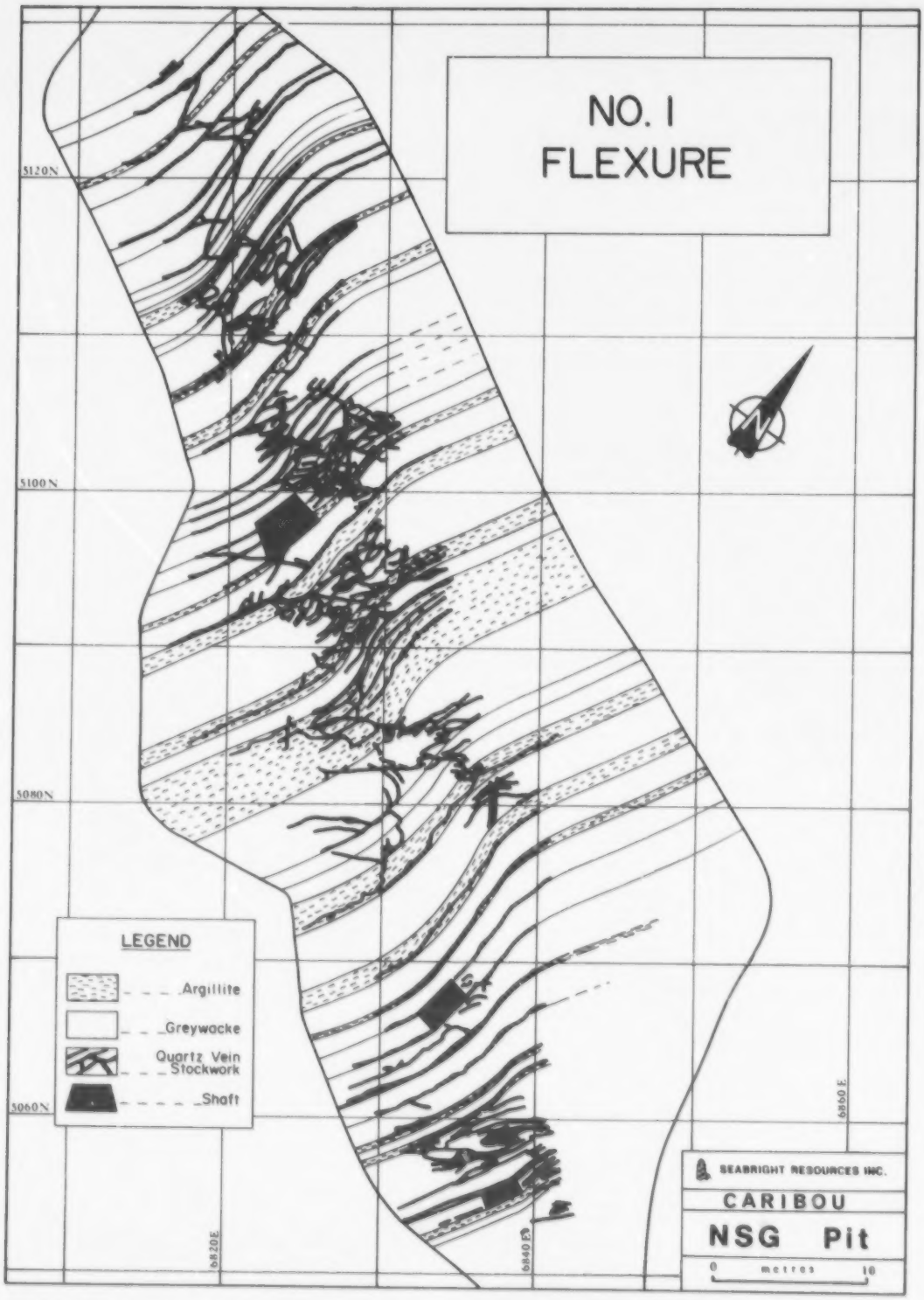

Figure 2. Surface map of the Main Zone ore body, Caribou deposit (geology is modified from work of Seabright Exploration geologists). Note the anastomosing network of quartz veins that occupy the NW-SE structure, but that within this zone the veins appear to have a very pronounced conjugate orientation.

are of equant shape, contain approximately 50-70 volume % liquid and daughter minerals are absent. Type 1 inclusions are generally larger with average maximum dimensions of 20-40 μm; type 2 inclusions are 10-20 μm. In contrast to the above, type 3 inclusions are commonly vapour-rich, much more irregular in shape and highly variable in dimensions (i.e. <5 μm to 50-60 μm). They are clearly of secondary origin, having formed during subgrain development, and are not considered further.

A single sample of an ac-type vein has also been examined for comparative purposes. This sample, collected on the 500 foot level and well removed from any known mineralization, contains excellent two phase, equant to negative-shaped, 10-50 μm (up to 100-150 μm) fluid inclusions occurring as arrays outlining healed fracture planes (type 2). Several solid inclusions occur, but these have not been positively identified and none are considered daughter minerals.

DISCUSSION OF FLUID INCLUSION THERMOMETRIC DATA

Results of fluid inclusion thermometric determinations (obtained using a FLUID Incorporated-modified, United States Geological Survey gas flow, heating-freezing stage) for quartz samples from the Main Zone are summarized in frequency plots in Figures 3 and 4 and the following points are noted.

(1) Melting temperatures of CO_2 (Fig. 3a) range from -60.5 to -55.5°C with a prominent peak in the data at -57/-58°C. This indicates that the CO_2 phase is not pure (i.e., pure CO_2 melts at -56.6°C) and that CH_4 is present (up to approximately 10 mole %)

(2) Clathrate melting temperatures (Fig. 3b) range from +5 to +14°C. Values in excess of +10° C indicate that CH_4 is present and, therefore, limit the use of data in Collins (1979) for estimating salinities of the inclusions. Thus, the maximum values of <9 wt. % equivalent NaCl inferred from the clathrate melting temperatures should be considered as minimum estimates. In addition, first melting temperatures in the range of -50°C and -35°C indicate that additional dissolved salts (e.g. $MgCl_2$ and $CaCl_2$) are present.

(3) Last melting temperatures of ice (Fig. 3c) range from around -10 to 0°C. Although the presence of coexisting clathrate in these inclusions causes an apparent increase in salinities of the H_2O phase due to the preferential exclusion of dissolved salts from their structure, maximum values can be

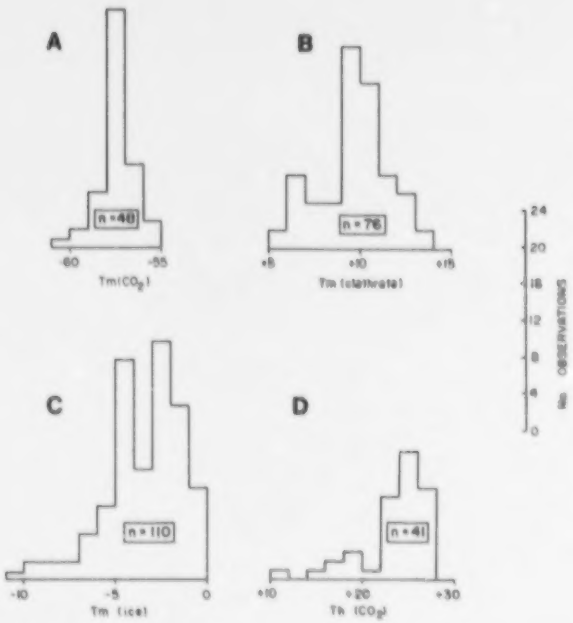

Figure 3. Histograms of thermometric data for type 1 and 2 fluid inclusions from Main Zone mineralization on the 500 and 800 foot levels at the Caribou deposit: (a) melting temperatures of CO_2, (b) melting temperatures of clathrate, (c) last melting temperatures of ice, (d) homogenization temperatures (to liquid phase) of CO_2.

calculated using the expression provided by Potter et al. (1978). Thus, the inferred maximum salinities for the inclusions are 14 wt. % equivalent NaCl, although most of the data (i.e. ≤ -5°C) indicate that salinities of < 7.5 wt. % equivalent NaCl are more common.

(4) Homogenization of the CO_2 phase was almost exclusively to the liquid phase with only four inclusions showing homogenization to the vapour phase. For those inclusions in which CO_2 homogenized by expansion of the liquid phase the temperatures (Fig. 3d) show a broad range from +10°C to about +28°C, corresponding to densities of 0.85 and 0.65 g/cc, respectively. The mean homogenization temperature of +25°C is equivalent to a density of 0.71 g/cc for the CO_2 phase. For the few inclusions where homogenization of CO_2 was by expansion of the vapour phase at about +25°C, density of the CO_2 phase is 0.24 g/cc.

(5) Final homogenization for the inclusions was invariably by expansion of the liquid phase. Although homogenization temperatures range from +120°C to nearly +300°C (Fig. 4), there is a pronounced maximum at +220 to 260°C. It should be noted that these temperatures are not corrected for pressure and are, therefore, considered minimum estimates.

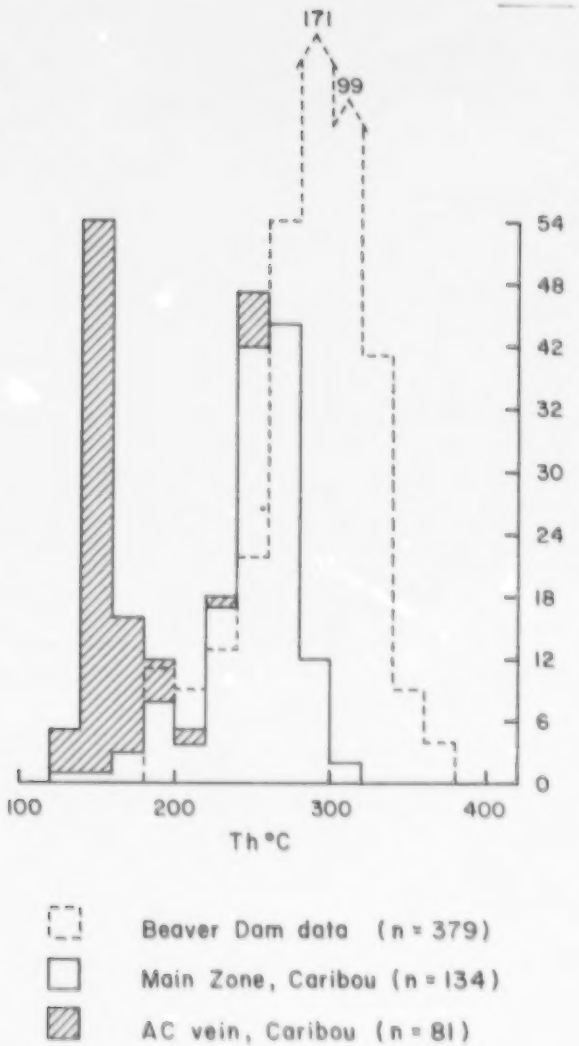

Figure 4. Final homogenization tempertures (all to liquid phase) of fluid inclusions from the Caribou and Beaver Dam deposits. Data for the Caribou deposit include type 1 and 2 inclusions from Main Zone mineralization and a single sample of quartz from an ac vein on the 500 foot level. Note the difference in the histogram peaks for homogenization temperatures for Beaver Dam versus Caribou.

(6) Using the average homogenization temperature of the CO_2 phase and estimating the proportion of CO_2 and H_2O at +40°C, the average XCO_2 of type 1 and 2 inclusions is estimated at 8 mole % using the method of Burruss (1981). This value of XCO_2 and the estimated salinity of the inclusions permits an estimate of the minimum pressure during vein formation in the Main Zone. Using available data for the H_2O-CO_2-NaCl system and assuming that fluid unmixing did not occur, a minimum pressure of 2 kbar is indicated. A similar estimate of pressure (i.e. 2-3 kbar) is obtained using the P-T-X(CO_2) graphs compiled by Brown and Lamb (1989).

(7) Only final homogenization data are shown for the sample of quartz from the ac vein (Fig. 4). Although there is a spread in the data from +120 to 260°C (Fig. 4), there is a pronounced maximum at 160 ± 10°C, a temperature considerably lower than that found for type 1 and 2 inclusions from the Main Zone. The inclusions behaved most inconsistently during freezing and consequently reliable data were not obtained. We note, however, that in some cases final melting of the only observed solid phase occurred at -53°C which indicates $CaCl_2$ to be the main dissolved salt component.

(8) Comparison of the fluid inclusion data from Caribou to those obtained from the Beaver Dam deposit has been discussed elsewhere (Kontak and Smith, 1989). Data from the two areas are remarkably similar with the most notable difference being for final homogenization temperatures (Fig. 4) (i.e. the peak for Beaver Dam being some 40°C higher than for Caribou). This difference is consistent with the presence of the early, high temperature mineral assemblage biotite-amphibole-Ca-rich plagioclase-tourmaline observed at Beaver Dam, but absent at Caribou. We also note that the data from Beaver Dam include both discordant and bedding parallel vein types and, hence, suggest that similar fluid reservoirs can account for all the major vein types so far examined in our studies of fluid inclusions from Meguma gold deposits.

CONCLUSIONS

Preliminary results of a fluid inclusion investigation of quartz vein material from the Main Zone at Caribou indicate that the dominant fluid was a low salinity H_2O-CO_2 (XCO_2 = 0.08) brine. Pressures attending vein formation are estimated at 2-3 kbar, but P_{fluid} must have exceeded $P_{lithostatic}$ at some time during stockwork development. Although at least two populations of fluid inclusions are recognized petrographically, they apparently represent the same fluid in terms of physio-chemical characteristics. In contrast, data for a sample collected from a late, barren ac vein indicate a notable difference from the fluid responsible for Main Zone mineralization with respect to its chemistry and much lower homogenization temperatures. Comparison of fluid inclusion data for types 1 and 2 inclusions to data for the Beaver Dam deposit indicates remarkable similarity, except for higher homogenization temperatures for the Beaver Dam material.

Finally, a point worth noting is that although fluid inclusions in the Meguma gold deposits are similar with respect to their physio-chemical features to fluid inclusions examined in other lode gold deposits, particularly those of Archean age (e.g. Robert and Kelly, 1987; Walsh et al., 1988), they differ in their lack of evidence indicative of fluid phase unmixing. The significance of this latter observation remains to be established, but it is noted because of the apparent discrepancy.

ACKNOWLEDGMENTS

The geological staff of Seabright Exploration Inc. are thanked for their continued support of our surface and underground investigations of Meguma gold deposits, in this particular case the Caribou deposit.

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METASEDIMENT-HOSTED PRECIOUS AND BASE METAL MINERALIZATION ALONG THE EAST KEMPTVILLE SHEAR ZONE AT FANNING LAKE, YARMOUTH COUNTY, NOVA SCOTIA

G. A. O'Reilly and P. K. Smith

INTRODUCTION

The Fanning Lake prospect (also called the North Carleton or Hilton gold prospect) has been known since the early 1900s and is located at the northeast end of Fanning Lake at Carleton, Yarmouth County (Fig. 1). The prospect was described as quartz fissure veins containing Cu, Pb and Zn sulphides with high levels of Ag and Au (Henderson, 1937). Exploration prior to the 1980s consisted of trenching followed by sinking of an 18 m deep shaft with a 4 m drift along a fissure vein in 1936. In 1939 a stamp mill was erected and 40 tons of rock were crushed but assay results were not reported. Samples containing ore-grade gold are easily obtainable from the dump material (e.g. 210 ppm Au, Chatterjee, unpublished data) and as a result renewed exploration attention has focused on the prospect and surrounding area.

Acadia Mineral Ventures Ltd. completed a 13 hole diamond-drill program at the prospect in 1988. Their intention was to search for extensions of a vein discovered in 1936 and to test several gold and base metal soil geochemical anomalies and northeast-trending geophysical (VLF) conductors discovered during their preliminary exploration surveys in the area. Their drilling showed that much of the mineralization is actually hosted within well developed quartz-sericite zones and not in true fissure veins.

Investigation of the drill core provides an opportunity to document the alteration and ore mineral assemblages in the recently recognized zones and examine the structural relationship of these zones. This project is part of an on-going study of granophile and base metal mineral deposits along the northeast-trending East Kemptville shear zone (EKSZ).The EKSZ is a series of continuous and/or en echelon structural breaks where faulting and ductile shearing have occurred (O'Reilly, 1988; Kontak et al., this volume; Fig. 1). The EKSZ extends from within the South Mountain Batholith northeast of East Kemptville to the Atlantic coast at Wedgeport, a distance of approximately 30 km.

METHODS

During the past two years, core from several of Acadia Mineral Ventures drillholes was examined by the authors and four holes were selected for detailed investigation. Diamond-drill holes FL-88-5 and FL-88-6 were drilled to depths of 152 m and 217 m respectively to test coincident Pb and Ag soil geochemical anomalies. Both drillholes encountered several intensely altered zones (~ 3 - 10 m thick) with associated sulphide mineralization. Drillholes FL-88-7 and FL-88-13 (132 m and 131 m respectively) were positioned to intersect a prominent northeast-trending VLF conductor. These drillholes intersected and bottomed in a thick breccia zone (>70 m) with pervasive fracture-controlled hematization and kaolinization.

Petrographic examination was carried out on samples from several of the zones in order to determine the alteration and ore mineral assemblages. Mineral identifications were subsequently verified with a scanning electron microscope (Bedford Institute of Oceanography, Dartmouth) and electron microprobe (Dalhousie University, Halifax). The geochemical signature of the alteration and mineralization was defined by analysis of several high-grade grab samples and from 51 half core samples (average core length of 0.6 m) from three separate zones from DDH FL-88-6: one zone with high Ag and Au values (15 m wide) and two zones with high Ag but low Au values (both 7.6 m wide). The samples were analyzed at the Minerals Engineering Center of the Technical University of Nova Scotia for an elemental suite consisting of CO_2, F, B, Li, Ag, Sb, As, Cu, Pb, Zn, Co, Bi, Cd, In, Sn and W. Analyses for Au are unpublished data held by Acadia Mineral Ventures Ltd.

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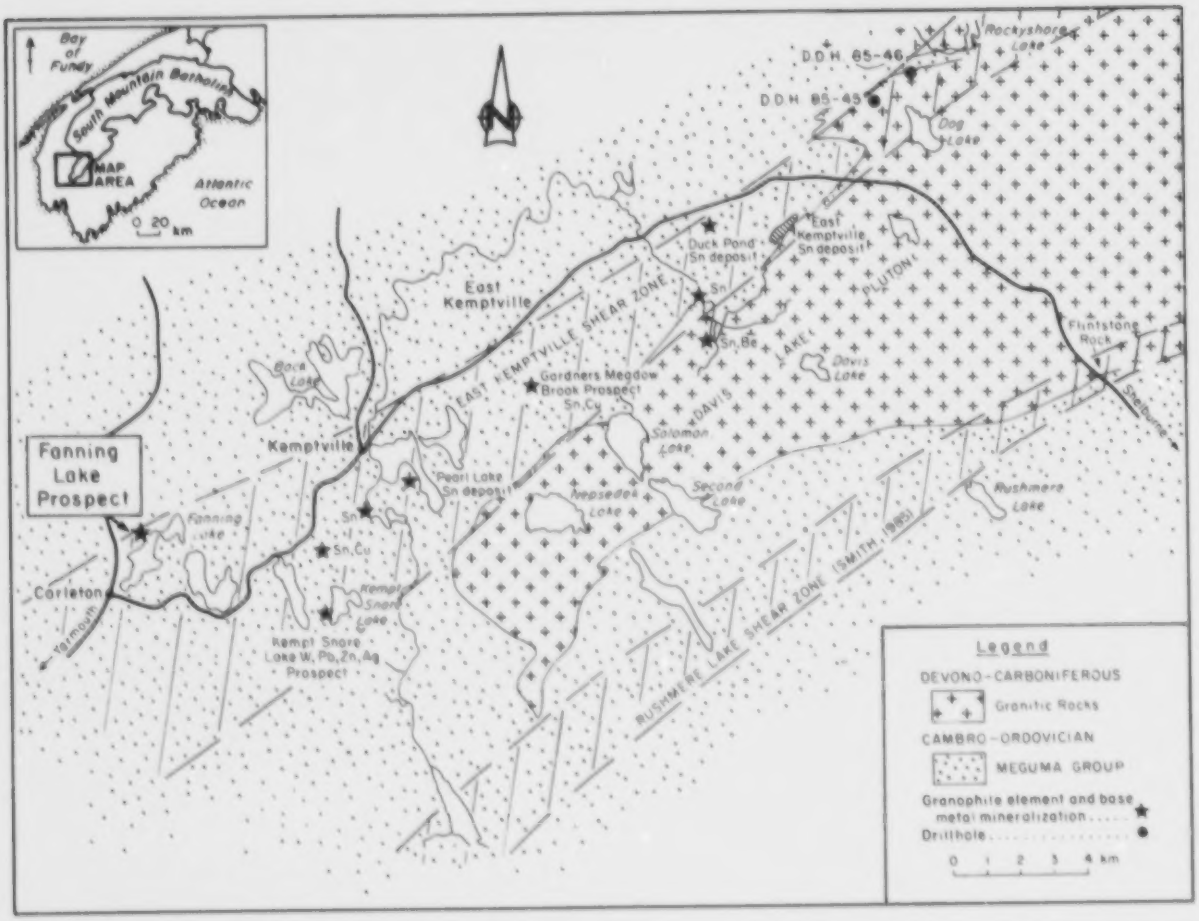

Figure 1. Geology map of the East Kemptville area showing the location of the Fanning Lake prospect relative to the Davis Lake Pluton, East Kemptville and Rushmere Lake shear zones, and the associated linear belt of granophile element and base metal deposits.

SUMMARY OF RESULTS

General Geology

The Fanning Lake prospect is hosted by steeply-dipping, fine- to medium-grained, light grey-green wacke, slate and argillite of the Cambro-Ordovician Goldenville Formation. Slate units display a well developed planar fabric which is assumed to be coincident with the northeast-trending regional fabric throughout southwest Nova Scotia. The prospect occurs within the EKSZ approximately 10 km west of the granitic rocks of the South Mountain Batholith (Fig. 1). In close proximity to the batholith the planar regional metamorphic fabric is overprinted by contact metamorphism related to granite emplacement, but in the Fanning Lake area there is no evidence of contact metamorphism.

Alteration Assemblage

Pervasive silicification, sericitization and carbonitization form alteration zones up to 15 m wide which overprint the regional planar fabric of the metasediment. Within each altered zone, silicification results in replacement quartz. However, in the most intensely altered central portion of the zones quartz has been introduced as veins (introduced quartz). Generally, replacement quartz zones immediately adjacent to zones of introduced quartz carry the greatest quantity of sulphides and the highest precious metal content. Sericite occurs with the replacement quartz but often decreases in abundance as silica content increases.

Siderite alteration occurs both with and without the sulphide mineralization. This carbonatization

was either long-lasting or periodic during formation of the alteration zones, as shown by the siderite occurring (1) pervasively disseminated throughout the alteration zones, (2) intimately associated with sulphides along shear planes and micro-fractures that cut earlier widespread carbonate alteration and (3) as late quartz-carbonate-chlorite veins that post-date the main mineralization stage.

Intense pervasive and fracture-controlled hematization and kaolinization occur within the thick brecciated zone in DDHs FL-88-7 and FL-88-13. These alterations accompanied brittle fracturing of the rocks, overprint the silicified and sericitized zones but post-date the mineralization. Similar brittle fracturing and alteration occurs along the EKSZ at the Duck Pond tin deposit, in two diamond-drill holes at Rocky Shore Lake and within the Rushmere Lake shear zone at Flintstone Rock (Fig. 1; Smith, 1985; O'Reilly, 1988). This alteration and fracturing at all of these locations are believed to be related to late movements and hydrothermal activity along these regional shear zones.

Ore Mineralogy

Pyrite, arsenopyrite and pyrrhotite occur finely disseminated (<1%) throughout most of the alteration zones. Where the alteration is most intense, the abundance of sulphides markedly increases (up to 20%) with the assemblage pyrite, arsenopyrite, chalcopyrite, galena, sphalerite and tetrahedrite. The galena, sphalerite and tetrahedrite occur as intergrowths mantling subhedral to euhedral pyrite, chalcopyrite and arsenopyrite, indicating that the former minerals formed later in the paragenetic sequence. Minor amounts of a Bi-Te mineral, native Bi and stibnite were recognized by electron microprobe. To date, no free gold has been noted.

Deformation

The alteration zones have no obvious direct structural control nor do they preferentially replace particular stratigraphic lithologies. The sulphide mineralization is often localized along micro-fractures and shear zones within the alteration zones. The micro-shears show features of both ductile (e.g. lensoid, sheared quartz) and brittle (e.g. ruptured grains, angular fragments) deformation. These features deform both original minerals and some secondary minerals suggesting that the alteration is, in part, syn-deformational. The sulphide minerals themselves are undeformed and either exploited these micro-shears during the waning stages of deformation or were more resistant to the deformation forces.

Geochemistry

Geochemical analyses from the three zones examined show high levels of As, Cu, Ag, Pb, Zn, Sb and CO_2. This elemental assemblage is consistent with the ore mineral assemblages described above but several of the inter-element correlations are not as strong as might be expected from the petrography. For example, the only Ag-rich phase noted is tetrahedrite (Cu, Sb, Ag, Fe sulphide) but in the geochemical data there is not necessarily a direct correlation between Ag and Sb. Several samples have anomalous Ag but only slightly anomalous Sb. Possibly, there is either compositional variation in the tetrahedrite throughout the prospect or there is an unrecognized Ag-bearing phase, such as native Ag.

Anomalous levels of Ag occur widely distributed throughout all three of the zones examined (up to 377 ppm). Comparable levels of Ag are found in the sulphide-rich quartz veins associated with greisen zones in the nearby Kempt Snare Lake prospect (Fig. 1; Soehl et al., 1989).

The Au levels in zones from the Fanning Lake prospect range up to 3732 ppb but are sporadically distributed. Samples from all three of the zones that were examined have comparable levels of base metals but samples from the Ag-Au zone are consistently more CO_2-rich. Whether or not the CO_2 enrichment has a direct bearing on the presence or absence of Au remains to be assessed.

ACKNOWLEDGMENTS

We would like to thank Acadia Mineral Ventures Ltd. for granting permission to examine and sample the drill core from the Fanning Lake prospect and for providing gold geochemical data. We are especially grateful to D. Rankin and D. Black of Acadia Minerals for several open discussions on the geology and mineral potential of this very interesting area.

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PETROGRAPHIC AND GEOCHEMICAL ASPECTS OF THE SOUTH MOUNTAIN BATHOLITH[1]

M. A. MacDonald, M. C. Corey, L. J. Ham and R. J. Horne

INTRODUCTION

The South Mountain Batholith (SMB) project began in 1984 as part of the Canada-Nova Scotia Mineral Development Agreement 1984-1989. The project's mandate was to produce detailed geological maps of the batholith and conduct detailed petrographic, mineralogical, geochemical, structural and metallogenic studies. A primary goal of the project was to make a preliminary evaluation of the mineral potential of the SMB since discoveries such as the East Kemptville (Sn-Cu-Zn-Ag) and Millet Brook deposits (U-Cu±Ag; Chatterjee, 1983) were thought to be only the "tip of the iceberg" (Giles and Chatterjee, 1986).

Numerous petrologic, geochemical, geochronological, metallogenic and petrogenetic studies have been conducted on the SMB during the past two decades (Clarke and Muecke, 1985; Clarke and Chatterjee, 1988, and references therein). However geological mapping associated with these studies was either reconnaissance in nature or detailed over restricted areas.

Geological mapping for this project started in 1985 and was completed during the 1988 field season. Geological maps (1:50 000 scale) for the entire SMB have either been published or are in final stages of preparation (see Table 1 for status of individual maps). In addition, numerous follow-up studies of the batholith have been initiated. This report highlights the more salient petrographic and geochemical features of the SMB.

DESCRIPTIVE CLASSIFICATION OF THE SMB

Large-scale granite mapping projects have previously been conducted in the Sierra Nevada Batholith, California (Bateman, 1988), and the Coastal Batholith of Peru (Cobbing et al., 1981). These projects used descriptive features (e.g. texture, mineralogy) to divide the granitoid rocks into map units and subsequently grouped these units into "sequences" or "superunits" on the basis of field relationships, geochronology and geochemistry. We have divided the SMB into eight rock types using similar descriptive parameters (grain size, texture, modal mineralogy), as outlined

Table 1. Status of geological mapping in the South Mountain Batholith project.

MAP TITLE	N.T.S.	OFM	PM	AUTHOR(s)
Halifax and Sambro	11D/05;/12		X(1987)	MacDonald and Horne
Mount Uniacke	11D/13		X(1987)	Corey
Windsor (East half)	21A/16E		X(1987)	Ham and Horne
Windsor (West half)	21A/16W;H/01	X(1988)	O	Ham
Chester	21A/09	X(1988)	O	Corey
New Germany	21A/10	X(1987)		Horne
Gaspereau Lake	21A/15;H/02	X(1988)		MacDonald and Ham
Bridgetown	21A/14	O		MacDonald and Ham
Milford	21A/11	O		Corey and Horne
Digby	21A/12	O		Ham
Kedjimkujik	21A/06	O		Horne
Weymouth	21A/05	O		MacDonald and Ham
Rossignol	21A/03	O		Corey and Horne
Wentworth Lake	21A/04	O		Ham and MacDonald

OFM-Nova Scotia Department of Mines and Energy (NSDME) Open File Map; PM- NSDME published map; X(1987)- published with date of release in brackets; O- in preparation.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

2 LUGR-leucogranite, FGLMG-fine grained leucomonzogranite, CGLMG-coarse grained leucomonzogranite, INT-intrusive suite, MBMG-muscovite-biotite monzogranite, BMG-biotite monzogranite, MP-mafic porphyry, BGD-biotite granodiorite.

Table 2. Average major and trace element contents and normative mineralogy for the eight rock types in the SMB. Data modified after Ham et al. (1989).

Rock Type	LUGR		FGLMG		CGLMG		INT		MBMG		BMG		GDIO		MP	
N	29		100		64		25		44		88		57		5	
Major Oxides (%)	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
SiO_2	73.51	0.89	73.90	1.20	73.22	1.07	72.82	4.09	71.46	1.08	69.51	1.68	67.10	1.73	68.96	1.17
Al_2O_3	14.67	0.49	14.27	0.47	14.23	0.48	14.66	2.39	14.62	0.36	14.82	0.40	15.51	0.73	14.72	0.37
Fe_2O_3(tot)	1.23	0.21	1.45	0.43	1.89	0.37	1.65	0.94	2.51	0.54	3.51	0.80	4.54	0.82	3.80	0.63
CaO	0.41	0.14	0.41	0.18	0.99	0.20	0.55	0.61	0.88	0.30	1.31	0.42	1.94	0.48	1.33	0.52
MgO	0.76	0.10	0.84	0.22	0.91	0.15	0.99	0.23	1.17	0.19	1.46	0.27	1.83	0.25	2.13	0.76
Na_2O	3.79	0.49	3.51	0.38	3.41	0.34	3.55	0.61	3.52	0.37	3.41	0.30	3.48	0.46	3.75	0.47
K_2O	4.10	0.45	4.48	0.34	4.68	0.25	4.66	1.18	4.63	0.34	4.26	0.39	3.69	0.41	4.07	0.30
TiO_2	0.07	0.05	0.13	0.08	0.19	0.06	0.14	0.09	0.34	0.09	0.48	0.13	0.67	0.13	0.54	0.19
P_2O_5	0.44	0.15	0.27	0.07	0.23	0.05	0.16	0.06	0.25	0.03	0.20	0.03	0.21	0.04	0.21	0.00
MnO	0.03	0.01	0.04	0.01	0.05	0.01	0.07	0.03	0.05	0.01	0.08	0.05	0.09	0.02	0.07	0.01
LOI	0.78	0.17	0.63	0.19	0.53	0.18	0.80	0.81	0.99	0.16	0.99	0.30	0.86	0.35	0.67	0.10
Normative Mineralogy	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Q	34.91	2.17	35.08	2.88	33.70	2.74	32.31	5.65	30.52	2.90	29.23	2.82	26.72	3.13	26.32	3.29
Or	24.43	2.89	26.70	1.99	27.83	1.49	27.79	7.00	27.55	2.05	25.46	2.28	22.03	2.47	24.23	1.89
Ab	32.35	4.11	29.85	3.16	29.03	2.79	30.25	5.18	29.92	3.08	29.09	2.53	29.70	3.86	31.93	3.83
An	0.00	0.00	0.52	0.94	1.43	1.10	1.74	3.04	2.74	1.54	5.22	2.05	8.29	2.36	5.15	2.39
C	4.02	0.62	3.49	0.73	3.05	0.64	3.17	2.40	2.84	0.56	2.73	0.62	2.81	1.04	2.28	1.32
En	1.91	0.36	2.12	0.56	2.27	0.38	2.48	0.58	2.92	0.46	3.67	0.68	4.61	0.64	5.29	1.87
Il	0.06	0.02	0.09	0.03	0.11	0.03	0.13	0.05	0.12	0.02	0.17	0.04	0.19	0.05	0.15	0.01
Mt	1.23	0.22	1.45	0.44	1.90	0.37	1.64	0.99	2.53	0.54	3.54	0.83	4.58	0.84	3.63	0.65
Hy	1.91	0.36	2.12	0.56	2.27	0.38	2.48	0.58	2.92	0.46	3.67	0.68	4.61	0.64	5.29	1.87
Ru	0.04	0.04	0.09	0.08	0.14	0.06	0.07	0.07	0.28	0.08	0.39	0.13	0.58	0.12	0.46	0.19
Ap	1.04	0.36	0.62	0.16	0.55	0.11	0.38	0.15	0.58	0.07	0.47	0.08	0.50	0.08	0.48	0.01
A/CNK	1.29	0.06	1.26	0.07	1.21	0.06	1.24	0.21	1.18	0.05	1.18	0.06	1.18	0.10	1.14	0.11
TTDI	91.68	0.83	91.63	1.63	90.56	1.47	90.35	4.80	87.99	2.38	83.78	3.18	78.44	3.19	82.48	2.59
C.I.	3.21	0.42	3.67	0.86	4.28	0.65	4.29	1.44	5.57	0.91	7.40	1.36	9.38	1.37	9.14	1.45
Trace Elements (ppm)	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Ba	61	73	146	148	196	91	170	122	351	86	491	112	667	127	909	205
Rb	589	226	338	110	301	84	185	54	255	37	184	31	149	29	196	26
Sr	19	13	31	27	48	22	47	56	80	24	118	27	171	32	118	22
Zr	39	16	60	28	82	31	60	28	123	20	159	36	193	36	154	42
Nb	22	8	12	4	12	3	8	3	13	3	11	2	12	2	11	1
V	3	3	5	6	9	5	9	7	20	10	35	13	55	14	43	16
Y	26	8	21	5	24	5	18	4	24	3	32	6	32	7	25	4
Ga	27	5	21	3	21	3	21	7	21	3	19	3	21	3	21	3
Cu	1	2	3	8	0	2	17	77	2	8	5	7	7	7	3	3
Pb	13	9	20	7	19	6	27	17	22	10	20	9	17	7	18	5
Zn	62	32	45	18	51	14	38	20	60	29	66	16	78	45	63	12
Hf	1.5	1.0	1.9	1.0	2.8	0.9	2.1	1.0	3.7	0.9	5.3	1.4	6.3	1.3	4.0	1.1
Ta	4.2	3.3	3.5	1.5	2.0	1.0	1.3	0.9	1.7	0.4	1.5	1.4	1.2	0.3	1.4	0.2
Sc	2.5	1.0	3.2	1.1	3.4	1.0	3.3	1.4	5.0	1.4	8.5	2.6	11.0	2.3	8.0	1.3
La	5	5	10	8	15	6	10	6	23	5	28	6	36	6	28	7
Th	4.1	2.8	6.2	4.2	9.2	3.4	5.0	3.0	12.7	3.2	11.5	1.9	12.9	1.6	11.6	2.6
U	3.9	2.1	7.8	5.3	5.5	3.5	7.2	16.4	4.5	1.6	3.8	1.2	2.9	0.7	3.9	0.6
Li	220	161	107	74	104	63	41	22	90	26	79	20	65	28	73	23
F	2317	1245	960	902	1013	665	245	141	826	320	612	124	667	239	658	42
B	26	17	25	11	26	17	25	8	26	8	24	10	20	9	25	5
As	2.5	1.3	6.3	8.6	2.9	2.8	2.3	3.9	11.7	52.1	4.1	3.7	3.2	4.1	4.4	2.5
Sn	27	10	19	9	13	7	9	4	10	4	7	4	5	3	10	4
W	7	3	6	6	3	2	3	6	2	4	1	1	1	1	1	0

N = number of samples; $\bar{X}$ = arithmetic mean; S.D. = standard deviation; $Fe_2O_{3(tot)}$ = total iron calculated as Fe_2O_3; LOI = loss on ignition; A/CNK = molecular ratio ($Al_2O_3/CaO + Na_2O + K_2O$); TTDI = Thornton tuttle differentiation index; C.I. = colour index; LUGR = leucogranite; FGLMG = fine grained leucomonzogranite; CGLMG = coarse grained leucomonzogranite; INT = intrusive suite; MBMG = muscovite-biotite monzogranite; BMG = biotite-monzogranite; GDIO = biotite-granodiorite; MP = mafic porphyry.

in MacDonald et al. (1988). The distribution of the eight rock types (LUGR-FGLMG-CGLMG-INT-MBMG-BMG-MP-BGD)[2] is given in Figure 1 (pocket on rear cover).

Concurrent petrographic and geochemical studies indicate the presence of several discrete polyphase plutonic centres within the SMB. Examples include the complexly zoned Halifax Pluton (MacDonald and Horne, 1988) and the pervasively metasomatised Big Indian Lake Polyphase Intrusive Suite (Corey, 1988). In addition, Horne et al. (1989) outlined discrete domains (plutons?) within the BGD and BMG envelope rocks. While more plutonic centres may exist, their delineation is inhibited by several

factors: (1) since the bulk of the SMB was emplaced circa 370 Ma ago (Clarke and Halliday, 1980; Reynolds et al., 1987), the identification of individual plutons using geochronological techniques is not possible; (2) synchronous cooling of the coalesced batholith also resulted in a paucity of chilled margins and definitive crosscutting field relationships making recognition of pluton margins difficult; (3) initial inspection of the geochemical data (Ham et al., 1989; Table 2) indicates the SMB has a moderately uniform composition (i.e. in terms of most major and trace elements) and therefore geochemical delineation of plutons is problematic.

PETROLOGY

Several thousand samples were collected, slabbed and stained for alkali feldspar. Representative samples were then point-counted to determine the proportion of quartz-alkali feldspar-plagioclase (QAP; albite is included with plagioclase). A contoured density plot of 452 QAP determinations from the entire SMB is presented in Figure 2a (fields after Streckeisen, 1976; Fig. 2b). The bulk of the SMB is composed of monzogranite and, to a lesser extent, granodiorite with minor syenogranite and tonalite. QAP plots of representative samples from each rock type are presented in Figures 2c-2i. The large scatter in each group reflects compositional variation, textural heterogeneities and varying degrees of metasomatic alteration (K-feldspathization, albitization). A plot of average QAP compositions for each unit is given in figure 2j. A trend of increasing A/P (i.e. degree of differentiation) is defined for the sequence BGD-BMG-MBMG-CGLMG-FGLMG, all with similar proportions of Q. A/P ratios in LUGR and INT resemble FGLMG, however LUGR is enriched in Q and INT is depleted in Q compared to FGLMG.

The following section summarizes some general petrographic features of the SMB. For more complete discussions, the reader is referred to MacDonald et al. (1988), MacDonald and Horne (1988) and Corey (1988). There are several systematic petrological variations in the sequence BGD-MP-BMG-MBMG-CGLMG-INT-FGLMG-LUGR. For example: (1) biotite decreases from >20% in some BGD to 0 in most LUGR; (2) muscovite increases from trace in most BGD, MP and BGD to >25% in some LUGR. Muscovite is predominantly a replacement product of alkali feldspar, plagioclase ± cordierite ± biotite in BGD, BMG and MP, whereas euhedral (primary?) muscovite increases in CGLMG, FGLMG and INT and may be more abundant than the replacement variety in some LUGR; (3) plagioclase is predominantly zoned and of oligoclase-andesine composition in BGD, MP, BMG and MBMG, whereas unzoned, albitic plagioclase increases in abundance in CGLMG and INT and predominates in FGLMG and LUGR; (4) alkali feldspar is perthitic, with string- and rod-type exsolution lamellae, in BGD, MP, BMG and MBMG. Patch-type exsolution increases in CGLMG and INT with non-exsolved (orthoclase?) varieties dominating in some FGLMG and most LUGR; (5) deuteric alteration effects, including feldspar replacement (K-feldspathization, hematization, albitization), chloritization and muscovitization, progressively increase from BGD to LUGR. This increase in alteration presumably reflects higher volatile content of the magmas and increasing interaction of crystalline rock with evolved fluids. All of these petrographic features indicate a trend of increasing differentiation in the sequence BGD-MP-BGD-MBMG-CGLMG-INT-FGLMG-LUGR.

GEOCHEMISTRY

The lithogeochemical analysis of the eastern portion of the SMB has been completed (Ham et al., 1989). A total of 456 samples from NTS map sheets 11D/05, 11D/12, 11D/13, 21A/09, 21A/10, 21A/15 and 21A/16 were analyzed for major oxides and a suite of 23 trace elements. Approximately 200 samples have been collected from the western portion of the batholith, however this sample set has only been partially analyzed because of budgetary restraints and is unavailable for release. Therefore, the geochemistry of rock types in the eastern SMB has been applied to the entire SMB. Average compositions and standard deviations for major and trace elements and normative mineralogy are presented in Table 2.

Major Elements

The sequence BGD-MP-BMG-MBMG-CGLMG-INT-FGLMG-LUGR is marked by progressive increases in the averages of SiO_2 (67.10-73.51%), Thornton-Tuttle Differentiation Index (TTDI; 78.44-91.68), Peraluminous Index (i.e. molecular $Al_2O_3/(CaO+Na_2O+K_2O)$; 1.18-1.39) and normative corundum (2.28-4.08) and a progressive decrease in Fe_2O_3 (4.54-1.23%), CaO (1.94-1.41%), MgO (1.83-0.76%), TiO_2 (0.67-0.07%), MnO (0.09-0.03%) and Colour Index (9.38-3.21). All of these parameters are consistent with progressive differentiation from BGD to LUGR. Al_2O_3, Na_2O and K_2O display no significant enrichment or depletion from BGD to LUGR. P_2O_5 values are erratic from BGD to FGLMG

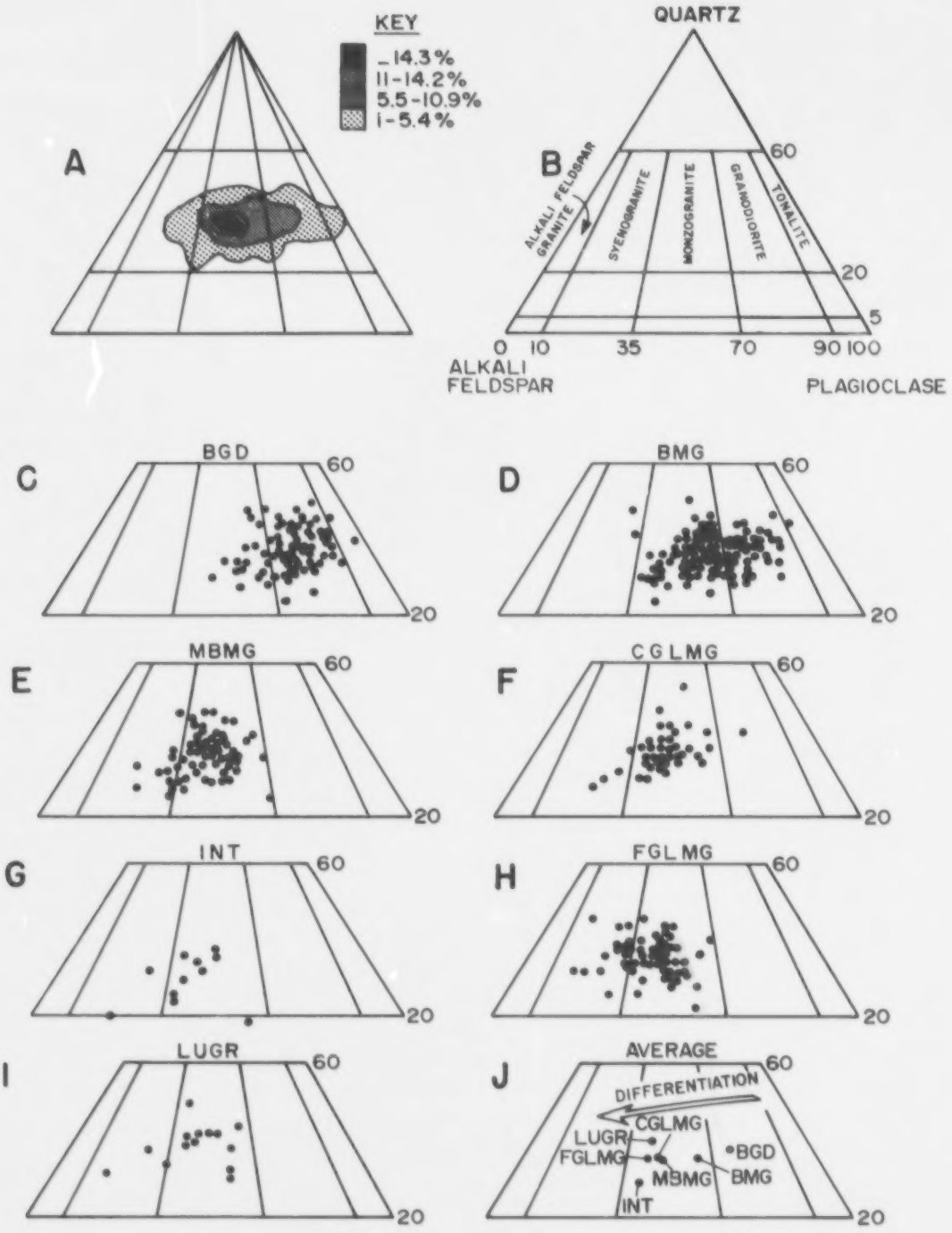

Figure 2. (a) Contoured QAP plot of 452 representative samples from the SMB indicating a predominantly monzogranitic-granodioritic composition; (b) fields after Streckeisen; (c) to (i) QAP plots of representative samples from the main rock types (mafic porphyry was omitted due to deficiency of samples); (j) average QAP compositions of main rock types showing the trend of increasing A/P ratio with differentiation. Abbreviations: BGD- biotite granodiorite; BMG- biotite monzogranite; MBMG- muscovite-biotite monzogranite; CGLMG- coarse grained leucomonzogranite; FGLMG- fine grained leucomonzogranite; INT- intrusive suite; LUGR- leucogranite.

(0.21-0.27%) but increase significantly in LUGR (0.44%).

Trace Elements

Several elemental averages display compatible behaviour and decrease with increasing differentiation from BGD to LUGR, including (all trace elements reported in ppm) Ba (667-61), Sr (171-19), Zr (193-39), V (55-3), Hf (6.3-1.5), Sc (11.0-2.5), La (36-5) and Th (12.9-4.1). Elements showing incompatible behaviour (i.e. increase with progressive differentiation from BGD to LUGR) include Rb (149-589), Ta (1.2-4.2), Li (65-220), F (667-2317), Sn (5-27) and W (1-7). Elements with no consistent variation between the various rock units include Y, Cu, Pb, Zn, As and B. U increases erratically from BGD to FGLMG (2.9-7.8) and is relatively depleted in LUGR (3.9). Nb and Ga have the same concentrations in BGD and FGLMG (Nb-12, Ga-21) and are enriched in LUGR (Nb-22, Ga-27).

Bivariate, log-log plots for Sr vs CaO and Zr vs TiO_2 are given in Figures 3a and 3b, respectively. The linear trends displayed by the majority of rocks (e.g. BGD to FGLMG) and progressive depletion with increasing differentiation (e.g. increasing TTDI) can best be explained by fractional crystallization (Cocherie, 1986) with the removal of biotite (TiO_2), accessory zircon (Zr) and plagioclase (CaO, Sr). This strongly coherent geochemical behaviour was previously noted by McKenzie and Clarke (1975) who concluded that the SMB represented a single co-magmatic suite. However, as stated previously, our mapping has outlined discrete plutons within the SMB. Although detailed evaluation of the lithogeochemistry is pending, it appears that some of these plutons have subtle, yet distinct, geochemical fingerprints that can best be detected using multivariate statistical techniques (Horne et al., 1989).

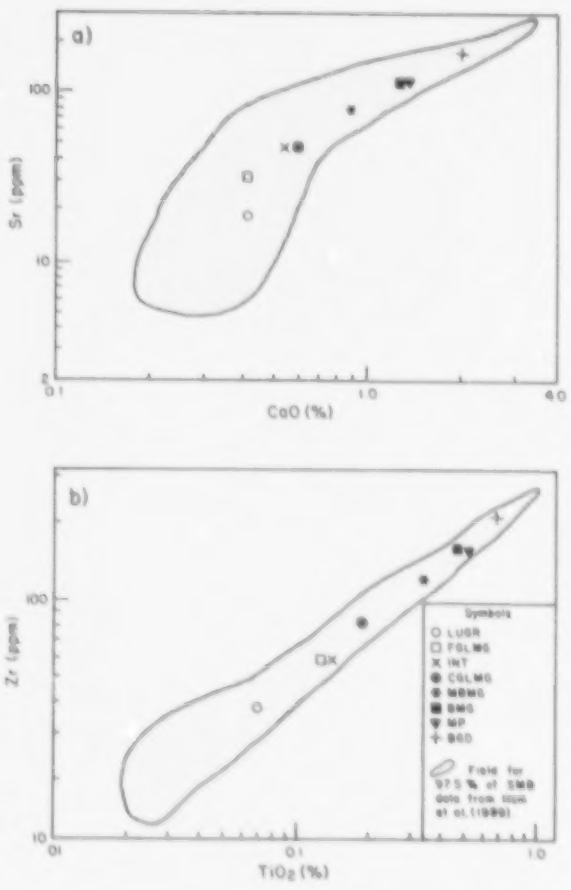

Figure 3. Bivariate, log-log plots for (a) Sr vs CaO and (b) Zr vs TiO_2 showing the strongly coherent geochemical trends for the entire SMB data set (N=458). Average compositions of the eight main rock types are also plotted. Linear trends for the sequence BGD to FGLMG indicate that fractional crystallization was the dominant process in the lesser evolved rocks whereas the deflection in the trends from FGLMG to LUGR suggests alternate processes were active in the most evolved rocks.

CONCLUSIONS

The SMB has been divided into eight rock types on the basis of purely descriptive features (i.e. texture, grain size and modal mineralogy). The sequence BGD-MP-BMG-MBMG-INT-CGLMG-FGLMG-LUGR is marked by systematic petrological and geochemical variations and defines a trend from least differentiated (BGD) to most differentiated (LUGR). Several discrete plutons have been delineated within the SMB but assignation of additional pluton boundaries is problematic because of a lack of clear-cut field relationships and varying geochronology. A lack of highly variable geochemical trends necessitates the use of multivariate statistical techniques to define geochemical "domains" (Horne et al., 1989) or plutons.

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PROGRESS REPORT ON THE SOUTH MOUNTAIN BATHOLITH PLEISTOCENE SURVEY[1]

P. W. Finck, R. M. Graves and F. J. Boner

The South Mountain Batholith (SMB) Pleistocene survey is a five year program designed to (1) map the distribution and provenance of surficial deposits overlying the SMB and (2) sample till on a 2 km square grid for the purpose of regional geochemistry.

GLACIAL GEOLOGY

Field mapping, including the collection of till samples, was completed by the end of the 1988 field season. There was no field work carried out during the summer of 1989. During 1989 the authors released the *Preliminary Glacial Geology of the South Mountain Batholith* (scale 1:250 000) as Nova Scotia Department of Mines and Energy Open File Map 89-018. This map shows the distribution of tills, landforms, residual granite, barren rock outcrop, ice contact and other glaciofluvial deposits. Cartography is in progress at MRMS to release it as a published, four colour map. The accompanying legend describes each map unit in detail and sets the stratigraphic framework for surficial deposits of the SMB. Release of this regional map will be followed by publication of more detailed 1:50 000 scale glacial geology maps with accompanying detailed marginal notes. Figure 1 shows the coverage of the 1:50 000 scale maps already released, those in press and in preparation. The 1:50 000 maps in preparation can

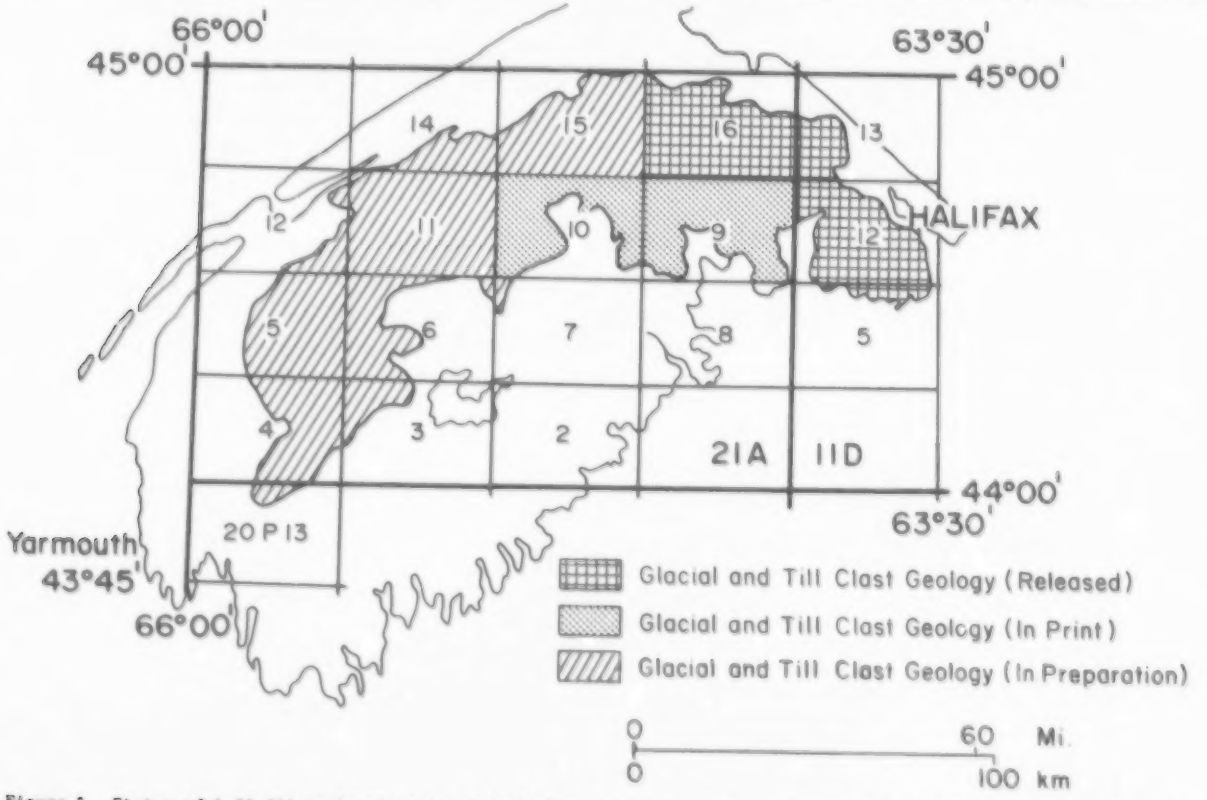

Figure 1. Status of 1:50 000 scale glacial and till clast geology maps being prepared for publication and/or Open File release as part of the SMB Pleistocene survey.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

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be viewed at the Nova Scotia Department of Mines and Energy, Mineral Resources Division, by contacting the authors.

GEOCHEMISTRY

Two thousand one hundred till samples were collected for analysis. A <0.063 mm silt-clay fraction and a heavy mineral concentrate from the <0.2 mm to >0.063 mm fraction of each sample were prepared at the CLIM Laboratories of the Atlantic Industrial Research Institute. Table 1 lists the elements to be analyzed, the till fraction to be analyzed for each element, and the present status of the analysis.

Due to a change in analytical techniques, analysis for Cu, Pb and Zn must be repeated for map sheets 11D/05, 12, 13 and 21A/09 prior to release of the data in order to guarantee a database with a consistent analytical background. Completion of the heavy mineral concentrates analysis and re-analysis for Cu, Pb and Zn are being delayed pending funding. No specific release date for the SMB tills geochemical database can be predicted at this time.

Table 1. Analytical status for the <0.63 mm till fraction and heavy mineral concentrates collected as part of the SMB geochemical program.

Map Sheets	Analytical Fraction (SMB tills)			
A=Analyzed N=Not Analyzed R=Re-analysis Pending	<0.63mm		Heavy Mineral Concentrates	
	Ni, Cr, Ba, Th, Se As, Rb, Sb, Ta, W, V, Fe, Mn	Cu, Pb, Zn	W	Sn
21A/03	A	A	N	N
21A/04	A	A	N	N
21A/05	A	A	N	N
21A/06	A	A	A	N
21A/07	A	A	A	N
21A/09	A	R	A	A
21A/10	A	A	A	N
21A/11	A	A	N	N
21A/12	A	A	N	N
21A/14	A	A	A	N
21A/15	A	A	A	N
21A/16	A	A	A	N
20P/13	A	A	N	N
11D/05-12	A	R	A	A
11D/13	A	R	A	A

REGIONAL GEOCHEMICAL SURVEYS[1]

R. F. Mills

BACKGROUND

A two year regional stream sediment survey was carried out on the northern mainland of Nova Scotia and Cape Breton Island in 1986 and 1987 to provide analytical data on stream water and two fractions of stream sediment (Fig. 1). Approximately 3300 stream sediment samples, including duplicates, were analyzed for 30 elements in the coarse (-60+230) heavy mineral separate fraction, and 16 elements in the (-230) fine fraction resulting in approximately 152,000 different elemental analyses. Some of these analyses were supplemented with fire assay analyses for gold. Stream waters were analyzed for U by fluorimetry and for F by specific ion electrode methods. Conductivity and pH measurements were also taken to help understand the digestive nature of some Nova Scotia streams and their possible relation to terrain and/or acid rain.

The primary objective of this project is to provide a database for the northern part of the

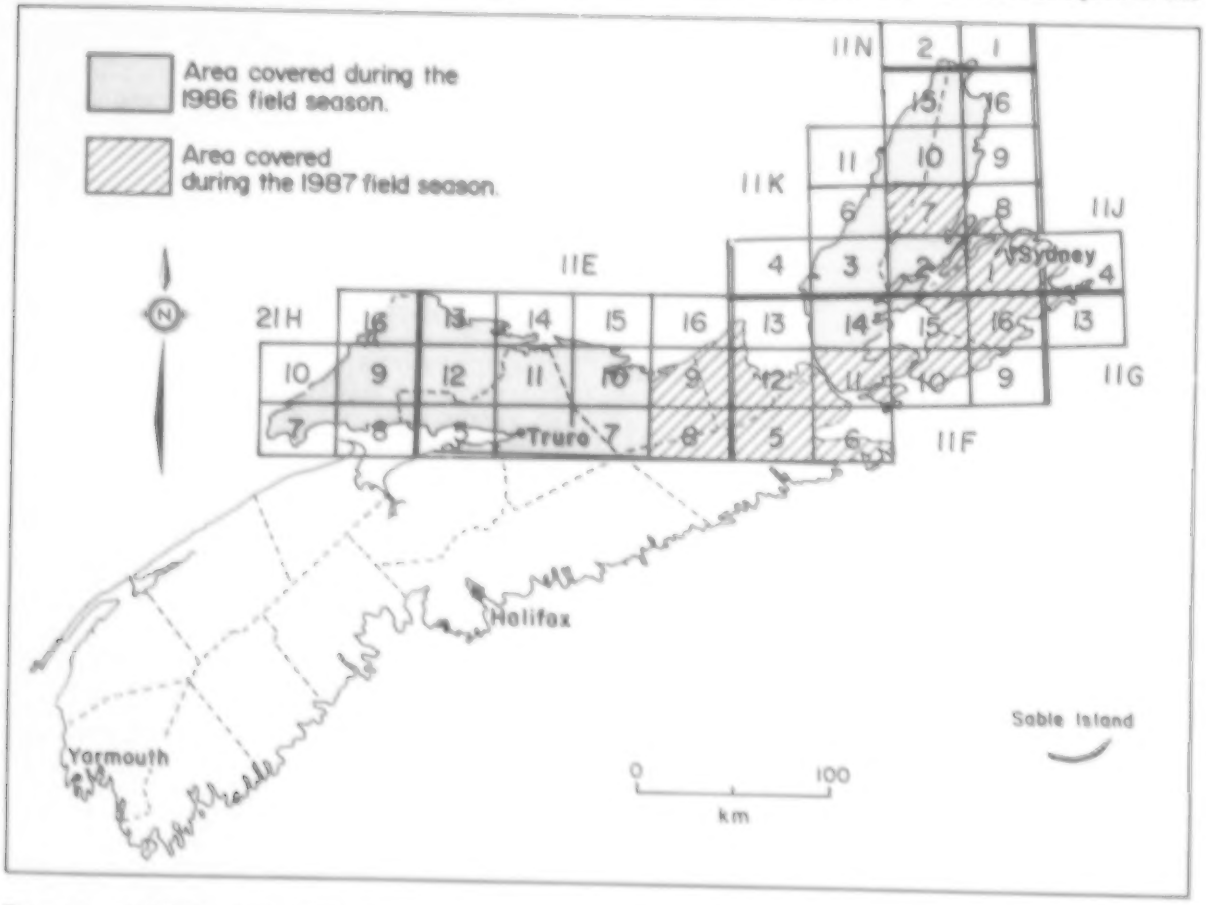

Figure 1. Fieldwork areas, 1986 and 1987.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement
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Province to be included in the regional *Nova Scotia Geochemical Atlas*. However, even before release of the Atlas, the database is an immediate aid for explorationists and geoscience research agencies working in the Province, as analyses and data representation from the survey will be released in Open Files. Hard copies of the data will be made available as will copies on 3.5 inch and 5.25 inch discs, and 600 foot tape cartridge.

SAMPLING TECHNIQUE

Stream sediment samples were passed through a -18 mesh nylon field screen and collected in a plastic pan along with all of the water used during sieving. The -18 mesh sample and water were poured into a 3 ml gauze polythene bag. This field sampling procedure minimized loss of fine gold by saving water used during sieving. Boyle (1979) has shown that water used during sieving may carry away fine gold. Air was removed after the samples were placed on a table for at least 48 hours to allow the fine gold to settle. Excess water was siphoned out of the bags and samples were packed for transport to the Technical University of Nova Scotia sample preparation lab. The samples were then washed and Rotap sieved into the respective coarse and fine fractions. The coarse fraction was also separated into a heavy mineral concentrate for analysis by Induced Neutron Activation Analysis.

Stream waters were collected in 250 ml plastic bottles and shipped directly to Bondar Clegg, Ottawa, for laboratory analysis.

ANALYTICAL METHODS

Two size fractions from each sample were analyzed. The -230 mesh (fine) fraction was analyzed for a suite of precious and base metals, and their granophile, siderophile and calcophile indicators. The -60+230 mesh heavy mineral (coarse) fraction was separated with heavy liquid (S.G. 2.95) and analyzed for a similar set of elements (Table 1). A flow chart of the analytical procedure is presented in Figure 2.

Erratic results from neutron activation analysis for gold resulted from methods of heavy mineral separation used during sample preparation in 1986. A residue of bromine left in some samples after tetrabromoethane heavy mineral separation produced erratic gold results (Lombard and Mills, 1987). Inaccurate gold analysis were replaced by results from fire assay analysis performed on the 1986 samples.

Table 1. Table of elements analyzed in 1986 - 1987 northern Nova Scotia stream sediment survey.

ELEMENTS ANALYZED			
-60 +230 HEAVY MINERAL CONCENTRATE	-230 FINE FRACTION	FIRE ASSAY	H_2O^-
XRF: Sn, Tl	INAA: Au	Au	Fluorimetry U
INAA: Au, As, Sb, Ag, Fe, Ni, Mo, Zn, Cd, Cr, Co, W, Se, Ta, Rb, Th, U, Tb, Yb, Ce, Ba, La, Hf, Ir, Sc	DCP-AES: Fe, Ni, Zn, Cd, Cu, Co, Ag, Bi, Mn, Li, Rb, Ba, Na, Al, K, V		SIE: F

The laboratory procedure for the 1987 field samples used methyl iodide (iodomethane) as the separation medium, which was diluted with acetone to the same specific gravity as tetrabromoethane (S.G. 2.95) so that results from both years would be comparable. This was determined from a pilot study performed in 1987 to determine which separation medium is best suited to extracting heavy minerals from stream sediments in Nova Scotia (Lombard and Mills, 1987).

Stream waters were filtered through a 45 μm filter and analyzed for U by fluorometry and F by specific ion electrode.

QUALITY CONTROL PROCEDURES

The sample vials were grouped into analytical batches consisting of 20 consecutively numbered samples (Mills et al., 1986). Included in every batch were two randomly chosen field duplicates, an analytical duplicate and a standard. The field duplicates determine field site variation, the analytical duplicates measure relative analytical precision and the standard measures the accuracy of the laboratory on a sample of known value. Stream water samples were the only exception to this format.

It was not practical to have an analytical duplicate (split sample), so the field duplicate was produced in the same manner. A graph was used to check each of the standards and analytical duplicates (splits) for each field crew in each type of analyzed medium to see that these values fall within acceptable limits.

PRIMARY AND SECONDARY DATA ANALYSIS

The database consists of several parts. First, preliminary statistics were run on each analytical

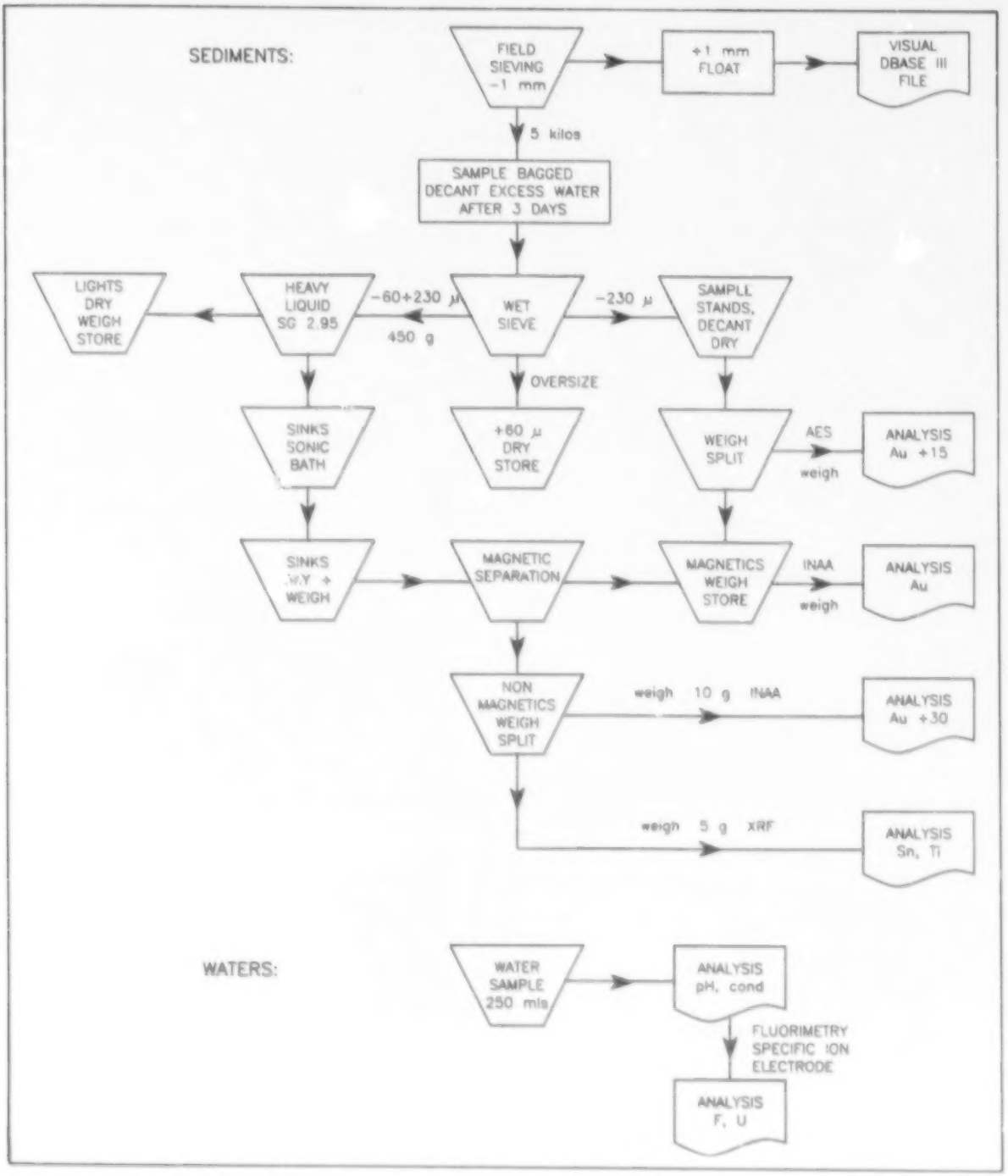

Figure 2. Flow chart of sample preparation and analysis (Rogers, personal communication, 1989).

dataset to ensure proper laboratory control. For each year a digitized location file was merged with: (a) the analyses file from the stream sediment heavy mineral concentrate (for 1986 and 1987), (b) the fine fraction analyses file (for 1986 and 1987), (c) the stream water analyses file (for 1986 and 1987), (d) a text file including sample site information (for 1986 and 1987) and (e) the 1986 fire assay file.

This produced nine separate merged files. Then each type of analysis was sorted into its appropriate 1:50 000 map sheet (Fig. 3), resulting in hundreds of separate files. In future, standards and outliers can be removed from the datasets for further univariate and bivariate statistics such as catchment basin analysis and regression analysis. The 1:50 000 sheet format gives the flexibility of running statistics on each file, or easily joining files to work at a larger (e.g. 1:250 000) scale.

The release of this geochemical data is to be divided into two parts, A and B. Part A of the release will consist of the analyses files, sample location maps for the analyses files and 1:250 000 scale plots of fine fraction gold. The digitized analytical data files will be presented as 1:50 000 scale map sheets. For ease of presentation, plots will be presented as three sheets in a 1:250 000 scale format. The advantage of presenting the release in two parts is clear: exploration and research agencies can benefit from direct release of the data in tabular form while further work on these datasets continues. Part B is to consist of further elemental symbol plots. Thresholds will be set for each plot produced using probability plots with histograms.

As an additional aid to companies or other government agencies that may want to do further analysis of these data files using their own statistical methods or software, the release will be made available in a Lotus 123, DBase III, or .PRN file for use on IBM format hardware. Magnetic media will be made available for different sized drivers.

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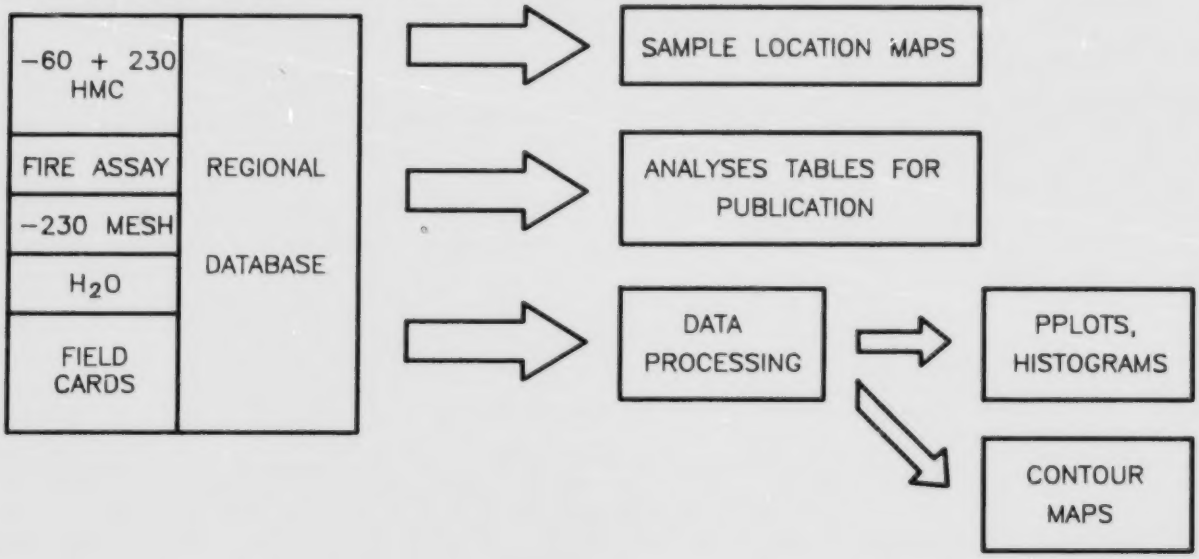

Figure 3. Simplified flow chart of generation and manipulation of computer files to produce separate map sheets.

PROGRESS REPORT ON REGIONAL GEOCHEMISTRY FOR THE GEOCHEMICAL ATLAS DATABASE[1]

P. A. Lombard

INTRODUCTION

Release of a series of open file reports is planned to present all geochemical data obtained from multi-media regional surveys conducted by the Nova Scotia Department of Mines and Energy (NSDME). The aim of the open file reports is to provide graphical illustration of multi-media geochemical anomalies. The data will be presented as a series of reports for each 1:250 000 scale National Topographic System (NTS) map sheet for each of 14 regional surveys (Table 1). The data sets and preliminary data analyses will be further subdivided into each component 1:50 000 NTS map sheet for ease of reference. Each report will contain details of sample media, methods for field collection, sample preparation, chemical analysis, survey extent and sampling density.

Geochemical Atlas Progress

The first stage of the Geochemical Atlas Project is designed to provide the raw data in tabular and graphical form. The next stage is the production of symbol intensity plots (1:250 000 scale) from the raw data in order to evaluate regional geochemical trends.

The first report, which consists of an Open File Report summarizing the 14 regional geochemical surveys, is scheduled for release in January 1990. The report contains histograms and symbol intensity plots for 12 elements analyzed following a 1982-83 survey of stream sediment geochemistry from NTS map sheet 11E.

Table 1. Regional geochemistry surveys in Nova Scotia.

Sample Media	Region	Dates of survey
Stream sediments	Northern Nova Scotia	1986-1987
	Northern Nova Scotia	1982-1983
	Highlands (N. S. & Cape Breton)	1971-1978
Lake sediments	Southern Nova Scotia	1985 (re-analysis)
	Eastern Nova Scotia	1983
	Southern Nova Scotia	1977-1978
Water samples		
(a) streams	Northern Nova Scotia	1986-1987
(b) streams	Northern Nova Scotia	1983
(c) lakes	Eastern Cape Breton	1983
Tills	South Mountain Batholith	1985-1988
	Northern Nova Scotia	1982-1986
	Meguma Zone	1977-1985
Biogeochemistry		
(a) tree limbs	Eastern Nova Scotia	1987
(b) tree bark	Eastern Nova Scotia	1987

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

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Geochemical Database

The geochemical database is digitally stored and supported by Datamine/GX software on a Compaq 386 personal computer (Lombard and Rogers, 1988). Digital files of all data can be made available on application to the author at NSDME on a cost of translation basis. Datamine is used to produce histograms (Fig. 1) and symbol intensity plots (Fig. 2) for each element, sample medium and component 1:5000 NTS map sheet. Basic statistics will also be provided with the tabular data listings. In the symbol intensity plots, each block represents the analysis of a sample location. The largest analytical value in each 1:250 000 NTS map sheet (e.g. 11E) is represented by a 2 cm^2 block. The remaining blocks are proportional in size to the largest analytical value in the 1:250 000 map sheet (Fig. 2).

GEOCHEMICAL COVERAGE

A database for 14 regional geochemical surveys has been established from surveys conducted over the past several years (Table 1). The database and Open File Reports will include the 14 regional geochemical surveys conducted so far in the Province.

REFERENCE

Lombard, P. A. and Rogers, P. J. 1988: Geochemical Atlas update: an inventory of regional geochemical surveys and compilation of private industry geochemical assessment reports; *in* Mines and Minerals Branch, Report of Activities 1988, Part A, eds. D. R. MacDonald and Y. Brown; Nova Scotia Department of Mines and Energy, Report 89-3, p. 143.

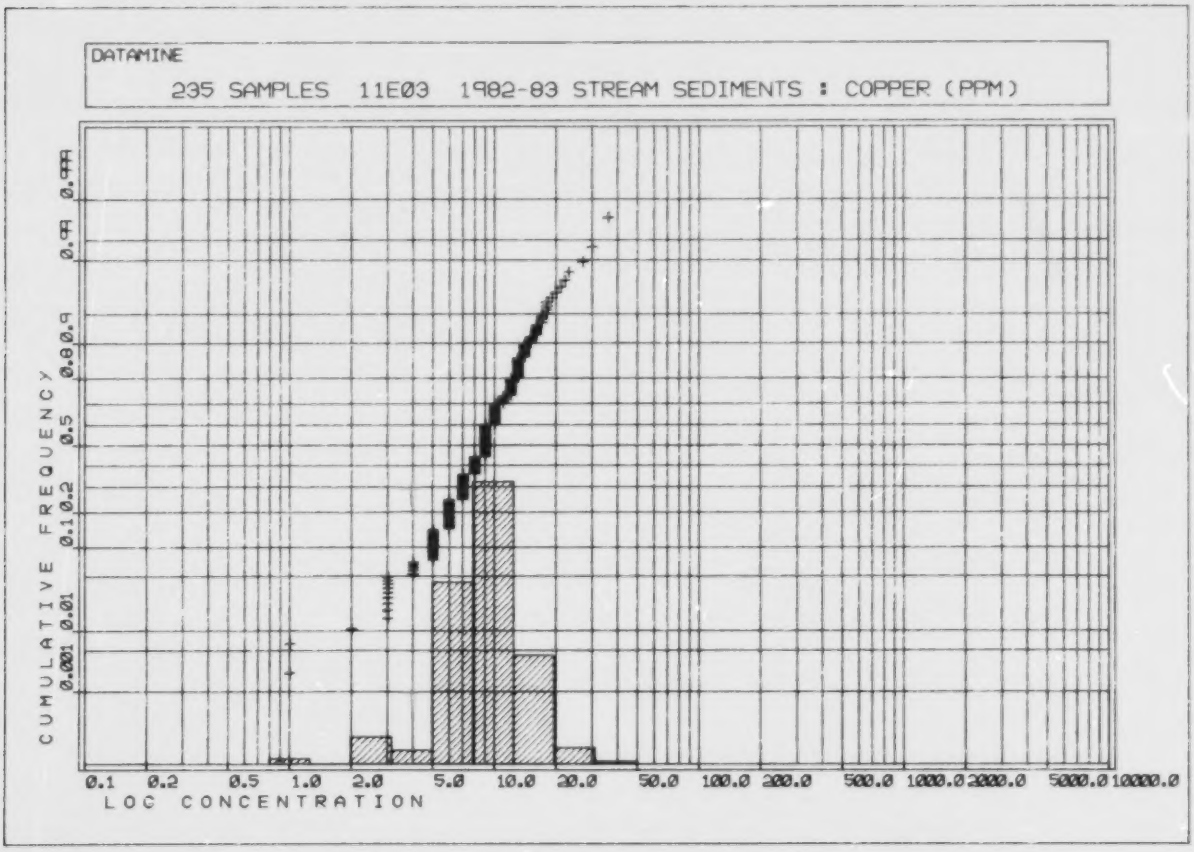

Figure 1. Example of a Datamine software cumulative frequency histogram for all the data points of the 1982-83 stream sediment survey within NTS sheet 11E/03.

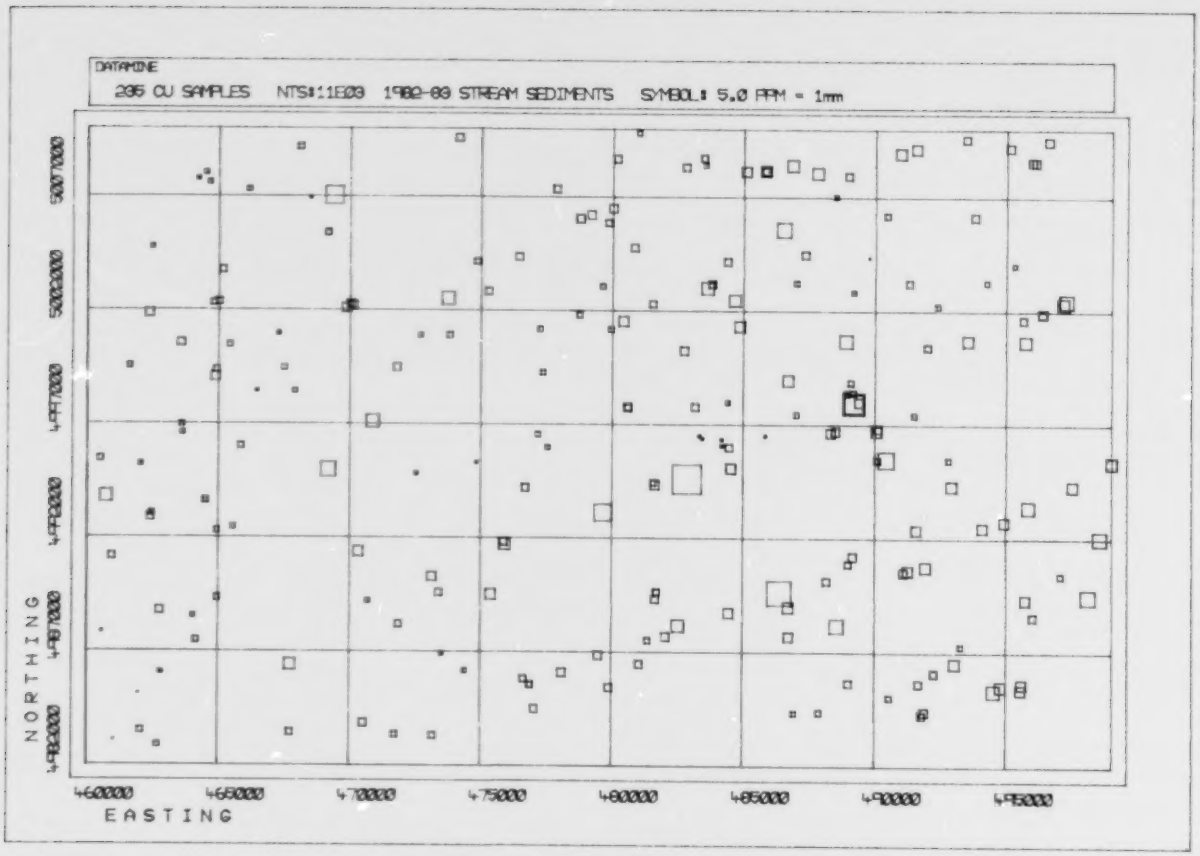

Figure 2. Example of a Datamine software 1:50 000 NTS map sheet variable element intensity plot. This particular plot shows Cu intensity for map sheet 11E/03. In the data set for 11E (1:250 000) the largest value is given the maximum 2 cm box size and the remainder are averaged accordingly.

INTERPRETATION OF MULTI-MEDIA GEOCHEMICAL SURVEYS: NORTHWEST TRENDS AND MINERAL POTENTIAL INSIDE AND OUTSIDE THE MEGUMA ZONE, EASTERN NOVA SCOTIA[1]

P. J. Rogers

INTRODUCTION

During the last five years almost all of the gold exploration in Nova Scotia has been conducted in the Meguma Zone (MZ), largely concentrating on historical gold producers found in Meguma Group rocks. One of the principal aims of the Follow-up Geochemistry Project, funded by the Geological Survey of Canada, is the application of geochemical exploration techniques to assist gold exploration both inside and outside the MZ. Exploration methods that have been applied to the search for gold in Nova Scotia include lake sediment surveys (Rogers et al., 1985; Rogers, 1988), biogeochemistry (Dunn, 1988; Dunn et al., 1989; Rogers and Dunn, 1989) and stream sediment heavy mineral surveys (Mills et al., 1987).

Anomalous patterns seen in the results from these surveys can be related to known mineralization, which therefore acts as a spatial control point for any unexplained geochemical patterns, which in turn can be correlated with areas of new gold potential in non-traditional areas. This report will concentrate on eastern Nova Scotia (Fig. 1) as a test area in defining new exploration targets using this multi-media modelling approach.

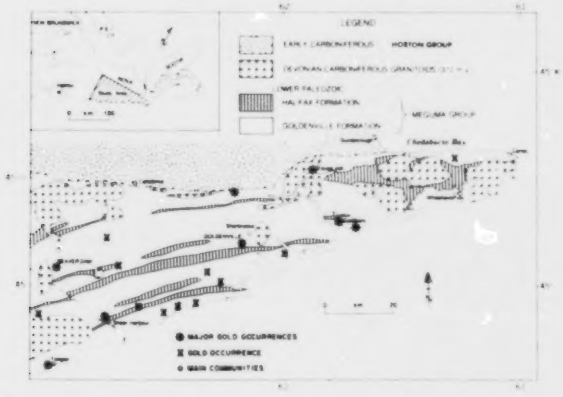

Figure 1: Generalized geology of the study area (from Dunn, 1988).

METHODS

Details of sample collection, preparation and analysis for the three geochemical media are given in the references listed above. It is worth noting here that the gold analysis for all surveys was performed using Instrumental Neutron Activation Analysis which allows comparison of response levels for each sampling method.

RESULTS

The lake sediment response (Fig. 2) is up to 529 ppb Au (at Lower Seal Harbour) with a clear spatial relationship of anomalous lake catchments to major known gold producers (Wright et al., 1988). Detailed studies of MZ lake sediments have identified free gold grains (Rogers, 1988) which may cause some lake anomalies. The lake sediment basins and the sample medium, gyttjä, are seen as geochemical sinks because of their ability to trap a mixture of chemical and mechanical weathering components (Rogers, 1988). The lake catchment basin study of Wright et al. (1988) indicates potential for mineralization in the area east of the Sherbrooke Pluton (Fig. 2).

The regional biogeochemical response (Fig. 3) in balsam fir twigs (up to 170 ppb Au) is also spatially correlated with known gold producers (Dunn et al., 1989) and is quite similar in pattern to that of the lake sediments (Rogers et al., 1985). Detailed studies at the Beaver Dam gold deposit demonstrate that biogeochemistry is capable of detecting gold anomalies in areas covered by thick till (Rogers and Dunn, 1989). The biogeochemical survey was purposefully extended into the till-covered areas of the St. Mary's Graben where significant gold anomalies occur over Horton Group (HG) rocks near Country Harbour (Fig. 3).

1 Funded by Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement

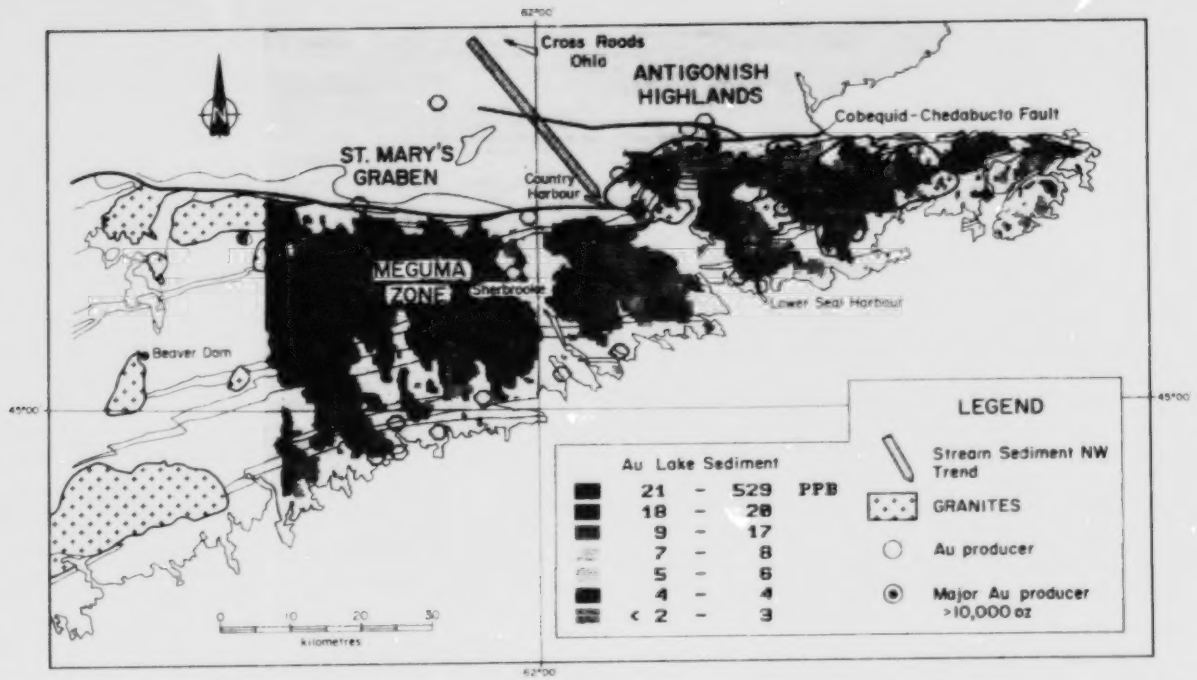

Figure 2: Lake sediment gold response. Computer-generated plot of lake catchment areas and gold values in ppb (from Wright et al., 1988).

The stream sediment survey design selected used two analytical fractions for gold in order to maximize information from each sample. More consistent and reproducible results are obtained from the -230 mesh (-62.5 μm) fraction, which forms the basis for this interpretation. The gold response indicates a number of anomalous areas in the Antigonish Highlands and surrounding Carboniferous envelope with maximum values around 200 ppb; one sample had 2400 ppb (Fig. 4). Further details of this survey are given by Mills (1989), who lists data from the whole of northern Nova Scotia including Cape Breton Island. Of note is the concentration of stream sediment Au anomalies in the Cross Roads Ohio area, where Northcote et al. (1989) have reported numerous bedrock gold occurrences.

DISCUSSION

Each geochemical method successfully outlines areas of anomalies spatially correlated to known gold- bearing areas. All three methods also indicate potential target areas for further exploration in eastern Nova Scotia. The contact areas of several granitoid bodies have distinctive anomaly patterns for gold, especially in lake sediments (Rogers, 1988) and biogeochemical samples (Dunn et al., 1989). The stream sediment survey area only has a limited overlap onto the MZ itself but still reveals some anomalies grouped near the easternmost granitoid bodies in the study area.

The large biogeochemical Au high in the St. Mary's Graben (Fig. 3) could be in part due to glacial smearing southeastward from the Cross Roads Ohio area . This interpretation is probably unlikely as the drumlin axes in this area are aligned north-south while the anomalies trend northwest - southeast. The large areal extent of the biogeochemical gold anomalies in the graben area strongly indicates a regional elevation of gold levels within HG rocks. The HG itself is thought to be largely derived from erosion of Meguma Group rocks. The area is worthy of follow up in light of the possible analogy to the Gays River placer deposit and the potential for similar placer deposits (Ryan et al., 1988).

The geochemical surveys also outline a number of regional trends which may be of interest in further extending areas of gold potential outside the traditional producing areas of the MZ. The stream sediment geochemistry outlines a prominent northwest-trending feature cutting across the Antigonish Highlands and the St. Mary's Graben

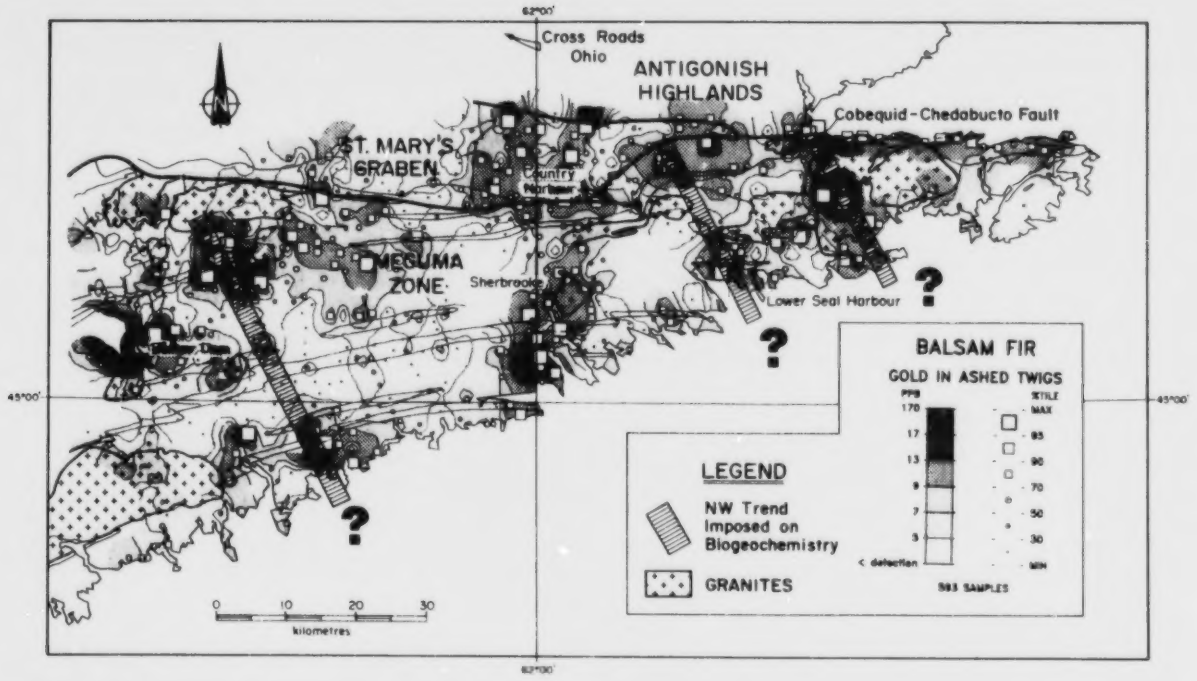

Figure 3: Biogeochemistry gold response. Computer contour plot of gold in ashed balsam fir twigs (from Dunn et al., 1988).

(Fig. 3). This area also has local gold-bearing tills (Stea, personal communication, 1989). Bonham-Carter et al. (1985) noted a significant relationship between northwest lineaments and gold deposits in the MZ. Giles (1986) also noted a prominent northwest feature near the Liscomb complex. This northwest feature is detected by its magnetic signature and it is along this trend that the Eastville lead deposit is situated. Kontak and Smith (1989) also note that the Main Zone at Caribou is a 10 - 15 m kink zone which trends 315° and plunges 37° SW.

Similar northwest-trending features have also been noted in Carboniferous rocks near Scotsburn (Patterson, personal communication, 1989). In this case the northwest trend is seen as anomalous levels of Ag, Cu, Pb and Zn in stream sediments and soils which cut across the regional strike (Rogers et al., 1986).

These northwest trends, though highly speculative, may be of great significance with regard to their role as focii of mineralization for precious and base metals. The northwest stream sediment trend intersects with the large grouping of biogeochemical anomalies near Country Harbour (Fig. 3). In the regional biogeochemistry (gold) map a northwest trend (Fig. 3) is extended to Lower Seal Harbour. This speculative move raises the additional question as to the age of these (?basement) features, which could extend out of the MZ as seen in the Scotsburn area (Patterson, personal communication, 1985). The trend of these features appears to be deflected by the Cobequid-Chedabucto Fault. These (basement?) features may therefore be older than the fault system.

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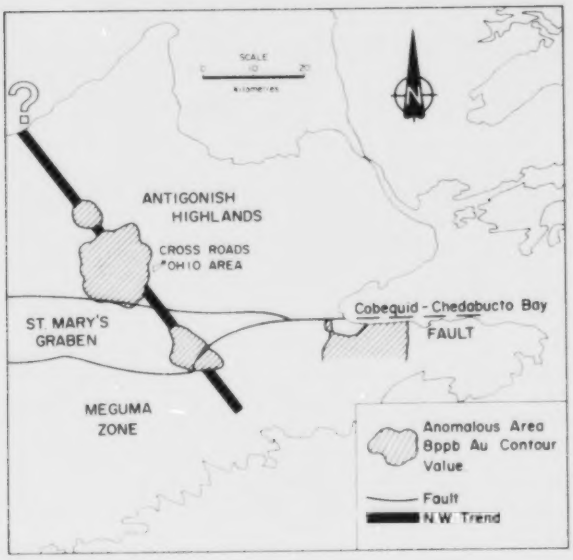

Figure 4: Stream sediment heavy mineral responses. Computer contour plot of gold in -230 mesh fraction showing northwest-trending geochemical feature crossing St. Mary's Graben into Antigonish Highlands (from Mills, 1989).

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CUMBERLAND AND PICTOU GROUP (UPPER CARBONIFEROUS TO LOWER PERMIAN) LITHOSTRATIGRAPHIC REVISIONS IN THE CUMBERLAND BASIN AND REGIONAL IMPLICATIONS[1]

R. J. Ryan and R. C. Boehner

CARBONIFEROUS STRATIGRAPHY

Carboniferous stratigraphic nomenclature in eastern Canada has evolved over the past 150 years and dramatic changes in the application of stratigraphic nomenclature have resulted in complicated and inconsistent use of stratigraphic terminology (e.g. lithostratigraphic, biostratigraphic and chronostratigraphic units). Defining and mapping formations at a local level have been relatively uncomplicated, however packaging them into regional groups has been problematic. A coherent, refined framework of lithostratigraphic units at the group level will simplify the regional correlation of laterally extensive packages of related rock units.

A thorough discussion of the evolution of stratigraphic nomenclature cannot be included in the space of this paper, however the nomenclature applied in the Cumberland Basin is summarized in Figure 1. Significant contributions to stratigraphic nomenclature were made by Bell (1912,1914, 1924, 1926, 1927, 1938, 1944, 1958); Shaw (1951a); Copeland (1959); Belt (1964, 1965); Kelley (1967); Barss and Hacquebard (1967) and Howie and Barss (1975).

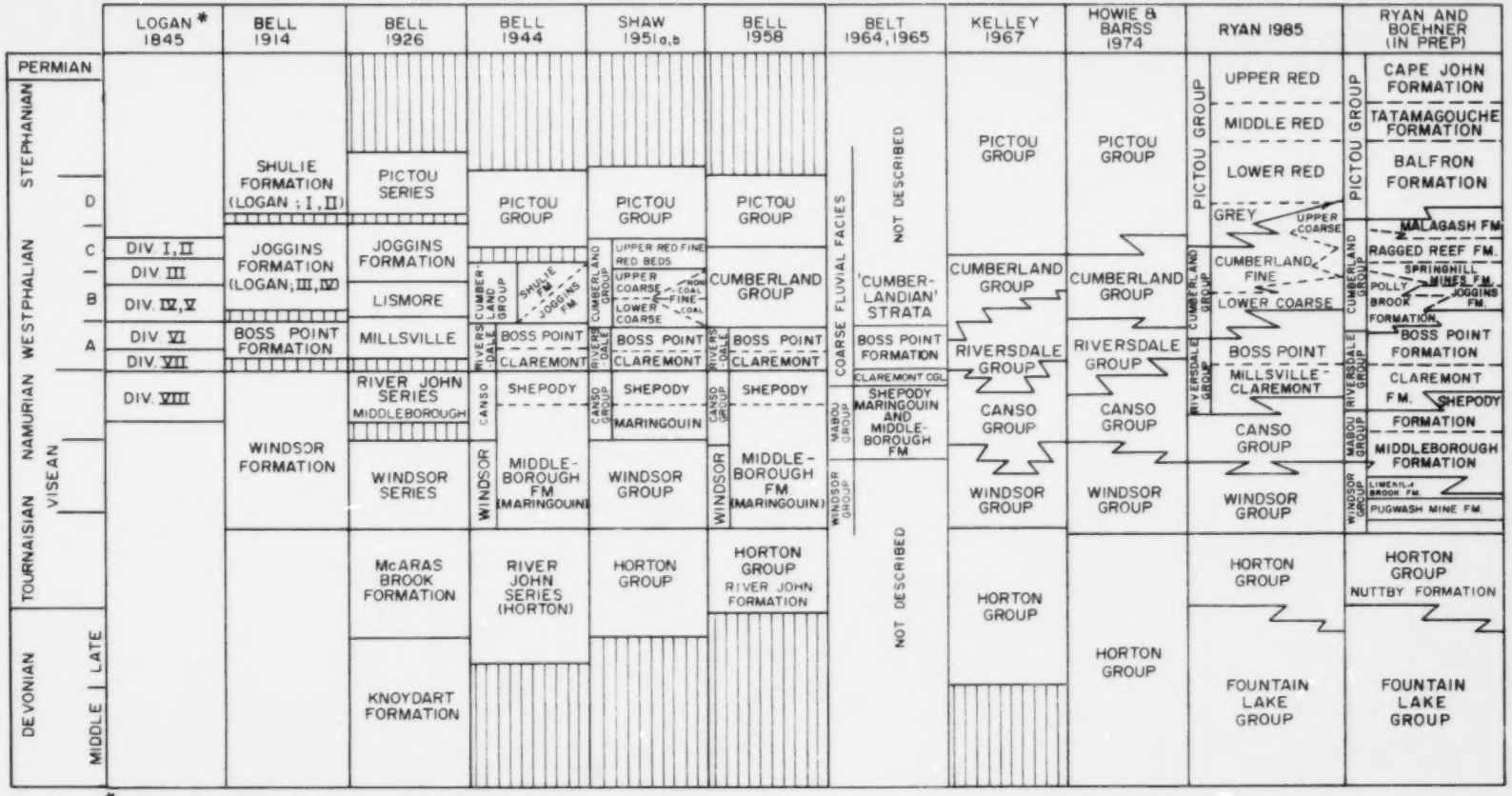
CUMBERLAND BASIN

Geological study of the Permo-Carboniferous strata of the Cumberland Basin, Nova Scotia (Fig. 2), was undertaken during the 1983-1988 field seasons as part of the Canada - Nova Scotia Mineral Development Agreement (1984-1989) and was funded by the Province of Nova Scotia. The study concentrated on the stratigraphy and sedimentology of the late Paleozoic rocks in this area, located north of the Cobequid Highlands in northern Nova Scotia, Canada. The Cumberland Basin contains the most complete sections of Westphalian to Stephanian strata in the Maritimes Basin, as well as type sections for the Cumberland and Pictou Groups and probably one of the best sections of strata assigned to the Riversdale Group. This study, therefore, was forced to deal with longstanding problems with lithostratigraphic group nomenclature.

The revised Carboniferous lithostratigraphy, based upon formations, to be proposed for the Cumberland Basin is important for several reasons: (1) the basin contains the type sections for both the Cumberland and Pictou Groups (sections 2 and 3 Fig. 2), (2) the scheme follows the general trend of previous workers to adapt, develop and improve the stratigraphic nomenclature on a formation level, (3) the lithostratigraphic units are defined in accordance with the North American Code of Stratigraphic Nomenclature (1983), (4) practical criteria to be used in assigning formations to groups are introduced (as a secondary priority) based on unifying lithologic characteristics and relationships that (i) accommodate broader lithologic variability, (ii) are not encumbered by age connotations and (iii) potentially may be extended to a revised regional nomenclature. Group boundaries and consequently formation assignment to groups are subject to future modification if necessary.

Notwithstanding the inherent problems, Bell's (1944) nomenclature has been so widely accepted and used that it would be imprudent to change all of the Carboniferous nomenclature for the Maritimes Basin solely on the basis of this study. Age, although important in any rock unit, cannot be a critical factor in the definition or recognition of modern lithostratigraphic units. The positions and nature of unconformities in the Maritimes Basin are inconsistent and insufficient in regional extent to serve everywhere as reliable group boundaries. A further exploration of the lithostratigraphic facies approach to group revision and definition as initiated by Belt (1964, 1965; Fig. 1) and applied in this study may help to resolve the inherent problems with the adapted and inconsistent stratigraphic schemes currently in use.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement



*Joggins section, tied to the lithostratigraphic assignments of this study.

Figure 1. Evolution of late Paleozoic stratigraphic nomenclature in the Cumberland Basin area, Nova Scotia, 1845-1989.

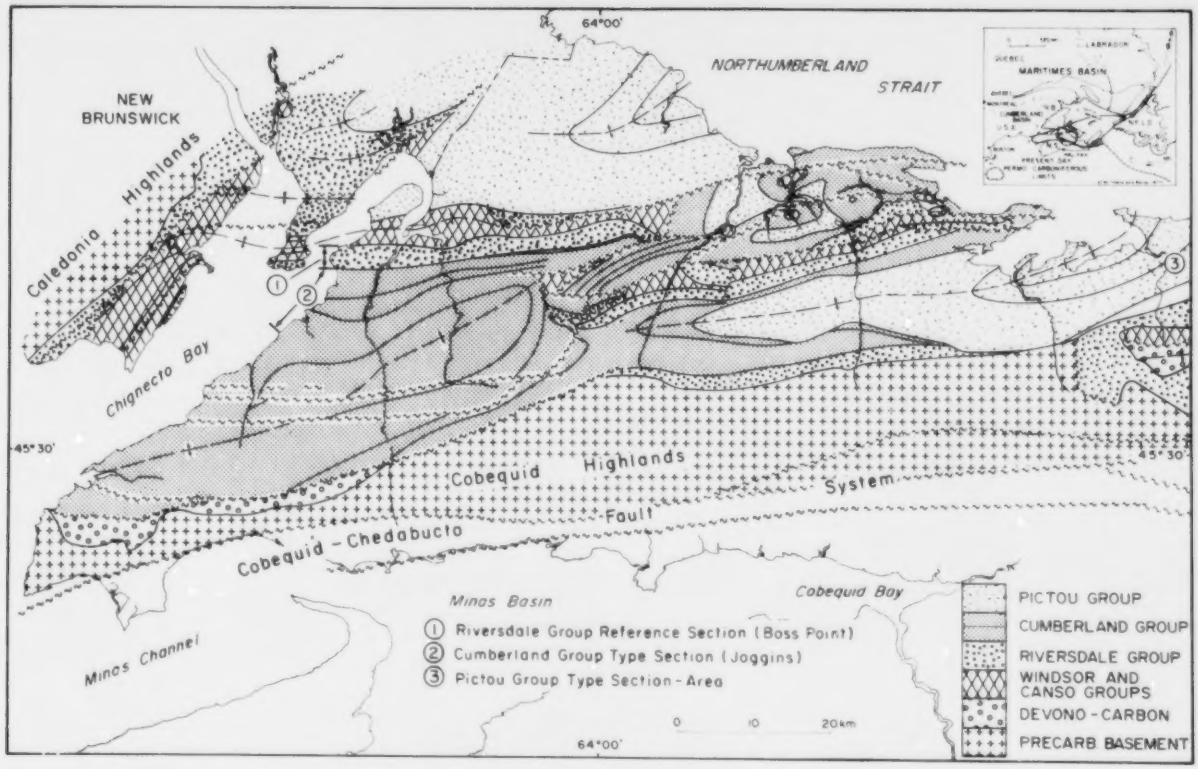
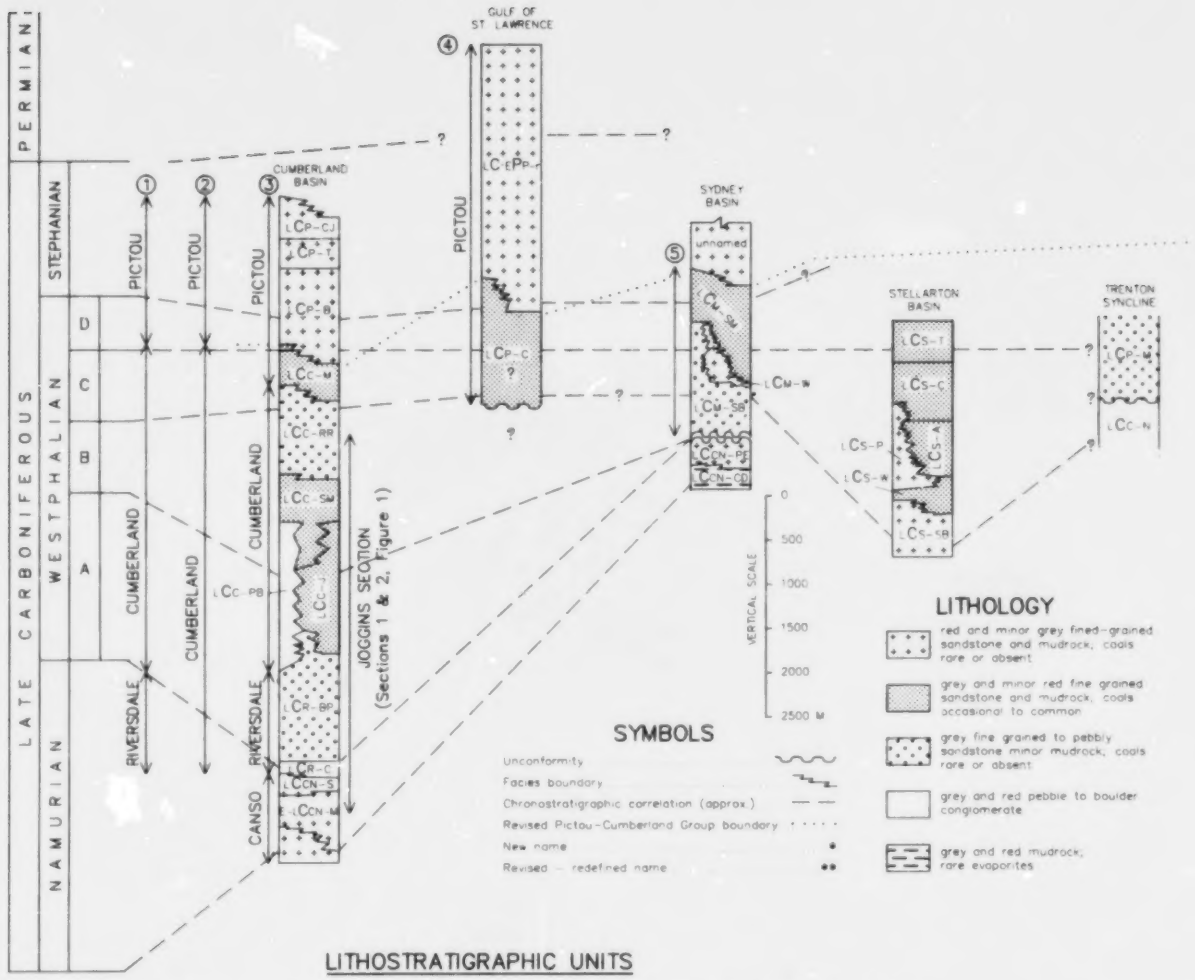


Figure 2. General geology and regional location map, Cumberland Basin.

CUMBERLAND AND PICTOU GROUPS

Shaw (1951a) modified a four-fold subdivision scheme introduced by Bell (1938) to divide the Cumberland Group in the Cumberland Basin (Figs. 1 and 2) into five major facies divisions: (1) the lower coarse facies; (2) the fine coal-bearing facies; (3) the fine non coal-bearing facies; (4) the upper coarse facies; and (5) the upper fine red facies. This contrasts with the earlier bipartite subdivision into a lower Joggins Formation and an upper Shulie Formation, which Bell (1914) introduced and whose validity was subsequently questioned (Bell, 1944). Copeland (1959) combined the coal- and non coal-bearing facies of Shaw (1951a) to make a four-fold facies subdivision of the Cumberland Group. The facies divisions of Shaw (1951a) were adapted by Copeland (1959) by merging the fine coal and non-coal bearing facies into a four-part subdivision: "lower coarse", "lower fine", "upper coarse" and "upper fine". Ryan (1985) subsequently employed a simplified three-fold subdivision of the Cumberland Group for mapping purposes: (1) lower coarse, (2) fine and (3) upper coarse (Fig. 2). The "upper fine red facies" of Shaw (1951a) were excluded from the Cumberland Group and have been considered to be part of the Pictou Group by several workers, including Belt (1965), Calder (1985), Ryan (1985) and numerous exploration geologists. No formal suggestion for such an amendment to the nomenclature was proposed. In this study, five new formations of the Cumberland Group are introduced: the Polly Brook, Joggins, Springhill Mines, Ragged Reef and Malagash Formations (Figs. 1 and 3). The "upper fine red facies" strata are part of the newly defined Ragged Reef and Malagash Formations. An option exists to include these formations in the Morien Group, if it were to be extended from the Sydney Basin through the Gulf of St. Lawrence area into the Cumberland Basin (Fig. 3).

Ryan (1985), in a preliminary report, suggested subdivision of the Pictou Group into four informal lithostratigraphic units: (1) grey beds, (2) lower redbeds, (3) middle redbeds and (4) upper redbeds. Ryan (1985) also suggested that the Pictou grey beds may be equivalent to the Cumberland Group fine non coal-bearing facies (Shaw, 1951a). In this study, the Pictou grey beds are designated the Malagash Formation of the Cumberland Group and



LITHOSTRATIGRAPHIC UNITS

CUMBERLAND BASIN

PICTOU GROUP

- LCP-CJ CAPE JOHN FORMATION**
- LCP-T TATAMAGOUCHE FORMATION*
- LCP-B BALFRON FORMATION*

CUMBERLAND GROUP

- LCC-M MALAGASH FORMATION*
- LCC-RR RAGGED REEF FORMATION*
- LCC-SM SPRINGHILL MINES FORMATION*
- LCC-J JOGGINS FORMATION**
- LCC-PB POLLY BROOK FORMATION*

RIVERSDALE GROUP

- LCR-BP BOSS POINT FORMATION
- LCR-C CLAREMONT FORMATION

CANSO (MABOU) GROUP

- LCCN-S SHEPODY FORMATION
- ?-LCCN-M MIDDLEBOROUGH FORMATION

GULF OF ST. LAWRENCE REGION

PICTOU GROUP

- LCEPP-r 'P.E.I. redbeds'
- LCEPP-C 'COAL MEASURES' (CORR. MORIEN GP.)

SYDNEY BASIN

MORIEN GROUP

- LCM-SM SYDNEY MINES FORMATION
- LCM-W WADDENS COVE FORMATION
- LCM-SB SOUTH BAR FORMATION

CANSO (MABOU) GROUP

- LCCN-PE POINT EDWARD FORMATION
- LCCN-CD CAPE DAUPHIN FORMATION

① Revised this study, Cumberland Basin
② Possible future revision if Riversdale is abandoned
③ Bell (1944)
④ Pictou Group (Borns & Hacquebard, 1967; Hacquebard, 1986)
⑤ Morien Group (Boehner and Giles, 1982)

STELLARTON BASIN

STELLARTON FORMATION (GROUP)

- LCS-T THORBURN MEMBER
- LCS-C COAL BROOK MEMBER
- LCS-A ALBION MEMBER
- LCS-P PLYMOUTH MEMBER
- LCS-W WESTVILLE MEMBER
- LCS-SB SKINNER BROOK MEMBER

TRENTON SYNCLINE

PICTOU GROUP

- LCP-M MERIGOMISH FORMATION

CUMBERLAND GROUP

- LCC-N NEW GLASGOW CONGLOMERATE

Figure modified after Naylor et al. (1989).

Figure 3. Upper Carboniferous-Lower Permian nomenclature and correlation, Nova Scotia and Gulf of St. Lawrence area.

the Balfron, Tatamagouche and Cape John Formations of the Pictou Group replace the lower, middle and upper redbeds, respectively.

The proposed criteria for assignment of formations to the Cumberland and Pictou Groups in their type areas in the Cumberland Basin are summarized in Table 1. In the subsequent publications, these new formations (Fig. 1) will be introduced, defined and assigned to appropriate groups using these criteria. The revised groups are intended to contain, as far as possible, naturally related and associated formations. Transitional and interstratified contacts (vertical and lateral) undoubtedly occur and will necessitate arbitrary decisions on group assignment. Criteria therefore must be flexible and subject to revision as exceptional circumstances are encountered regionally.

arkose, grey to reddish-brown mudstone and siltstone, red to grey fine grained litharenite, coal seams from 0.01 m to 4.3 m thick, and thin bituminous black limestone and shale with bivalves. Formal designation of five formations within this group in the Cumberland Basin is proposed: Polly Brook, Joggins, Springhill Mines, Ragged Reef and Malagash Formations. Many of these formations are similar to the units used by Bell (1938) and Shaw (1951b).

The Cumberland Group in the type area has a maximum thickness in the range of 4000 m and has a variety of contact relationships including: (1) concordant and conformable, to disconformable with the underlying Boss Point Formation of the Riversdale Group; (2) unconformity with basement

Table 1. Lithologic criteria used for defining the Cumberland and Pictou Groups in their areas in the Cumberland Basin.

CRITERIA	CUMBERLAND GROUP	PICTOU GROUP
Coal-bearing:	frequently but not always	rarely
Red facies:	subordinate	dominant
Grey Facies:	dominant	subordinate
Conglomerate:	locally abundant	rare
Fine facies:	subordinate-subequal	dominant
Facies variation:	rapid, diverse	limited and local
Contacts:	conformable to disconformable with Riversdale,	conformable to unconformable with Cumberland Group and correlatives,
	unconformable with older Carboniferous and basement rocks,	unconformable with older Carboniferous and basement rocks
	conformable to disconformable with Pictou strata	

DISCUSSION AND CONCLUSIONS

The Cumberland Group is of heterogeneous lithology comprising; red and grey boulder to pebble polymictic conglomerate, grey medium- to coarse-grained cross stratified subarkose to sublitharenite, grey to reddish-grey coarse grained

rocks of the Cobequid Highlands; (3) angular unconformity with underlying Windsor Group and probably Canso Group strata. The Group is conformable to disconformable with overlying Pictou Group rocks. Using the assignment criteria previously outlined, in conjunction with those proposed for the Pictou Group, the following

formations would be correlative with, and/or subdivisions of the revised Cumberland Group (Fig. 3): (1) all or part of the Morien Group and Stellarton (Group) Formation, (2) probably the lower formations of the Petitcodiac Group (e.g. Boss Point, Salisbury and Richibucto) in New Brunswick, and (3) part of the Barachois Group in Newfoundland.

Rocks of the Malagash Formation have previously been assigned to the basal beds of the Pictou Group (Bell, 1926) and informally referred to as the Pictou grey beds by Ryan (1985). These rocks probably correlate with the Merigomish Formation of Yeo (1987) in the Trenton Syncline near Pictou. Malagash Formation strata have also been assigned to the fine non coal-bearing facies of the Cumberland Group by Shaw (1951a) and the Cumberland fine facies of Copeland (1959) and Ryan (1985).

The Malagash Formation in the reference section (River John) was originally included in the Pictou Group as defined by Bell (1926, 1944). Based on lithological, stratigraphic and sedimentological similarities these strata are herein re-assigned and included as part of the Cumberland Group. Regional studies, however, may establish an assignment to the Morien Group if it can be extended as a definable unit from the Sydney Basin to the Cumberland Basin. If the Morien Group cannot be extended, then the option exists that it be abandoned and replaced by the Cumberland Group.

The Pictou Group has been correlated with or has encompassed all or parts of regional and local units of Westphalian C to early Permian age (Howie and Barss, 1975), including the Morien Group (Series) and the Stellarton Group (Formation), and was extended by Barss and Hacquebard (1967) to include the Prince Edward Island Redbeds (van de Poll, 1983). Using the assignment criteria proposed for the Pictou Group in this study (Table 1), the revised group will comprise a complex redbed sequence of mudrocks, sandstone and pebbly sandstone with rare thin limestone. The units that would be included in the Pictou Group are restricted to the Balfron, Tatamagouche and Cape John Formations in the Cumberland Basin, the Prince Edward Island Redbeds (Pictou Group 'Prince Edward Island redbeds' of van de Poll, 1983) and equivalents, including the undivided Permo-Carboniferous redbeds in the Sydney Basin (Fig. 3), the Broad Cove Formation in western Cape Breton Island, the Tormentine Formation at the top of the Petitcodiac Group in New Brunswick and perhaps the Cap-aux-Meules Formation in the Magdalen Islands. The revised Pictou Group excludes the coal-bearing section in the Gulf of St. Lawrence which is age and lithologically correlative with the Morien Group (Hacquebard, 1986). The Pictou Group (revised) redbeds may reach a maximum thickness of up to 3000 m in the Gulf of St. Lawrence area.

It is further recognized that the Riversdale Group, Boss Point Formation lithofacies are difficult to separate from the revised Cumberland Group (similar to the situation in New Brunswick, e.g. Petitcodiac Group) whose criteria were previously outlined. In this study, the Riversdale Group is tentatively retained until further regional work establishes its validity. Similar to the Morien Group, the revised Cumberland Group may eventually lead to the abandonment of the Riversdale Group if distinctive and substantive lithologic criteria for recognition cannot be established. If a regional group philosophy were adopted, then ultimately the Cumberland Group could encompass all the strata above the Mabou Group as defined by Belt (1964 and 1965), up to the base of the revised Pictou Group. In this situation the Cumberland Group would have a maximum thickness of 5000 m in the Cumberland Basin (exceptional). Regionally, thicknesses of 1500-2000 m would be typical. In its broadest application, the Cumberland Group could contain strata as old as late Namurian and as young as early Stephanian.

It is realized that these revisions do not resolve all the current inconsistencies in group and formation assignments and relationships of Late Carboniferous and Early Permian rocks in the region. Revisions and proposed criteria for assignment of formations to the Pictou and Cumberland Groups have regional implications and vary substantially from previous application. These ramifications and a complete stratigraphic framework for the region cannot be fully evaluated or proposed at this time. Consideration, however, has been given to the advantages and disadvantages of the revisions using a workable philosophy within the current standards of stratigraphic nomenclature. Several options and variations exist for a comprehensive revision of late Carboniferous lithostratigraphy, for example fewer regional groups with lithological coherency (partial or complete synonymy of Morien and (?) Petitcodiac Groups) versus more numerous local groups. This note is intended to initiate the discussion, debate and compromise that will be required to resolve these problems and avoid potentially regressive, ill-conceived or unnecessary changes.

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ECONOMIC GEOLOGY OF LATE PALEOZOIC - EARLY MESOZOIC BASINS IN NOVA SCOTIA: MID-WESTPHALIAN TECTONISM AND METALLOGENESIS[1]

R. C. Boehner and R. J. Ryan

INTRODUCTION

This synopsis of the mineral resources of Late Paleozoic and Early Mesozoic basins in Nova Scotia (Figs. 1 and 2) and the concept of a genetic link with mid-Westphalian tectonics is extracted from contributions to the Decade of North American Geology project (Ryan and Boehner, in prep.; Boehner and Fowler, in prep.). The latter compilations attempt to synthesize the essential character of the resources within a milieu of evolving genetic models of mineralization, regional tectonics and sedimentation. Various and frequently incompatible models and interpretations have been presented and illustrate the rapid evolution of mineral deposit research. Every effort has been made to balance the treatment of these complex and often controversial subjects by incorporating and integrating the most recent information available.

Discussions of energy resources have been removed from this synopsis due to space limitations and diagenetic-epigenetic mineral deposits are emphasized. The mineral resources of

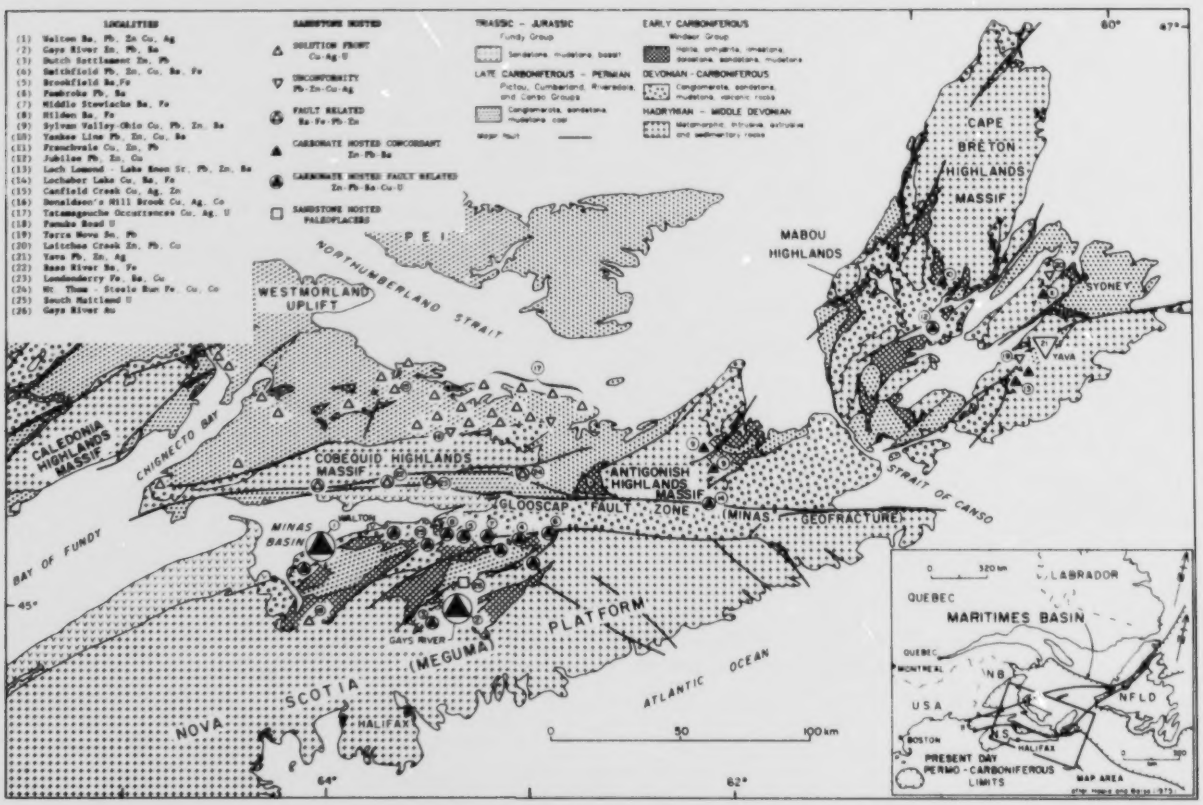

Figure 1. Metallic mineral deposits and occurrences, and generalized geological map.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

NSDME Report 89-3

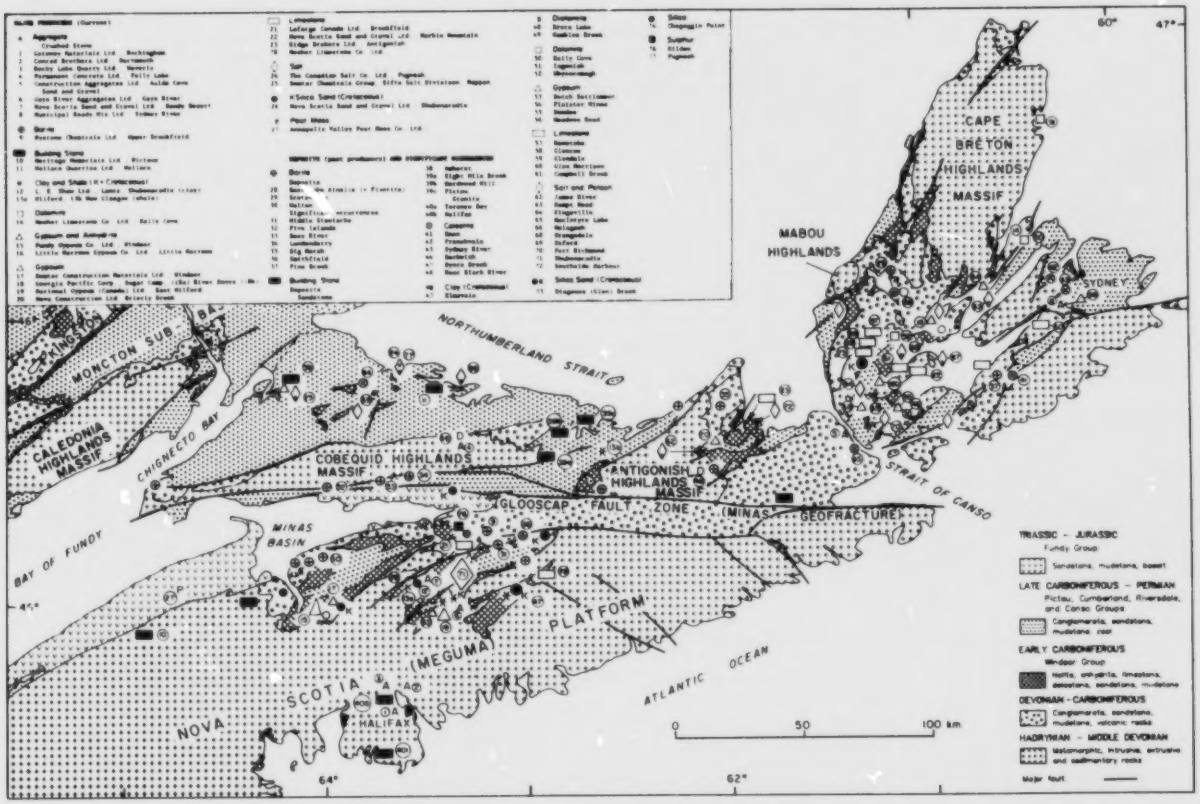

Figure 2. General geology and location map for industrial-nonmetallic mineral resources in Nova Scotia.

these basins are separated into two principal groupings: (1) metallic minerals and (2) industrial nonmetallic minerals. The metallic and related nonmetallic mineralization is further subdivided into: (a) sandstone-hosted and (b) carbonate-hosted, (i) discordant and (ii) concordant.

This synopsis will primarily address the possible temporal and genetic connections between various mineral deposition models involving an apparent tectonically controlled diagenetic-epigenetic origin. The term diagenetic is used in the extended sense of an intrabasinal mineralizing fluid source as suggested by Gustafson and Williams (1981) and thus overlaps somewhat with usage of the term epigenetic.

TECTONO-SEDIMENTARY HISTORY AND METALLOGENESIS

Late Paleozoic metallogeny is intimately linked to the complex sedimentary and tectonic history of the late Paleozoic and early Mesozoic to Cenozoic basins. The stratigraphy and tectonic setting of the basins are summarized diagrammatically in Figure 3. Late Paleozoic to Mesozoic rocks in Atlantic Canada record a complex history of sedimentation, tectonics and volcanism in the northeast Appalachians. The strata contained within these successor basins reach a maximum thickness of 12 km (Howie, 1988) in the central Gulf of St. Lawrence (Magdalen Basin). They are a complex molassic succession dominated by continental deposition (Fig. 3). Sediments were derived both locally (especially in the Late Devonian and Early Carboniferous) and regionally (Late Carboniferous) from the Appalachian Orogen. These transient source areas and shifting depocenters represent the waning stages of the Devonian Acadian Orogeny and the subsequent uplift of the orogen following the mid-Devonian docking of the Avalon Composite Terrane and the Meguma Terrane (Fralick and Schenk, 1981). The early Mesozoic records the initial rifting phase of the Proto-Atlantic Ocean and the late Mesozoic to Cenozoic records its subsequent opening. Nova Scotia is roughly bisected by, and straddles, the Cobequid-Chedabucto Fault System (Figs. 1 and 3) which separates the Avalon and Meguma terranes. Consequently the diversity of mineral deposits

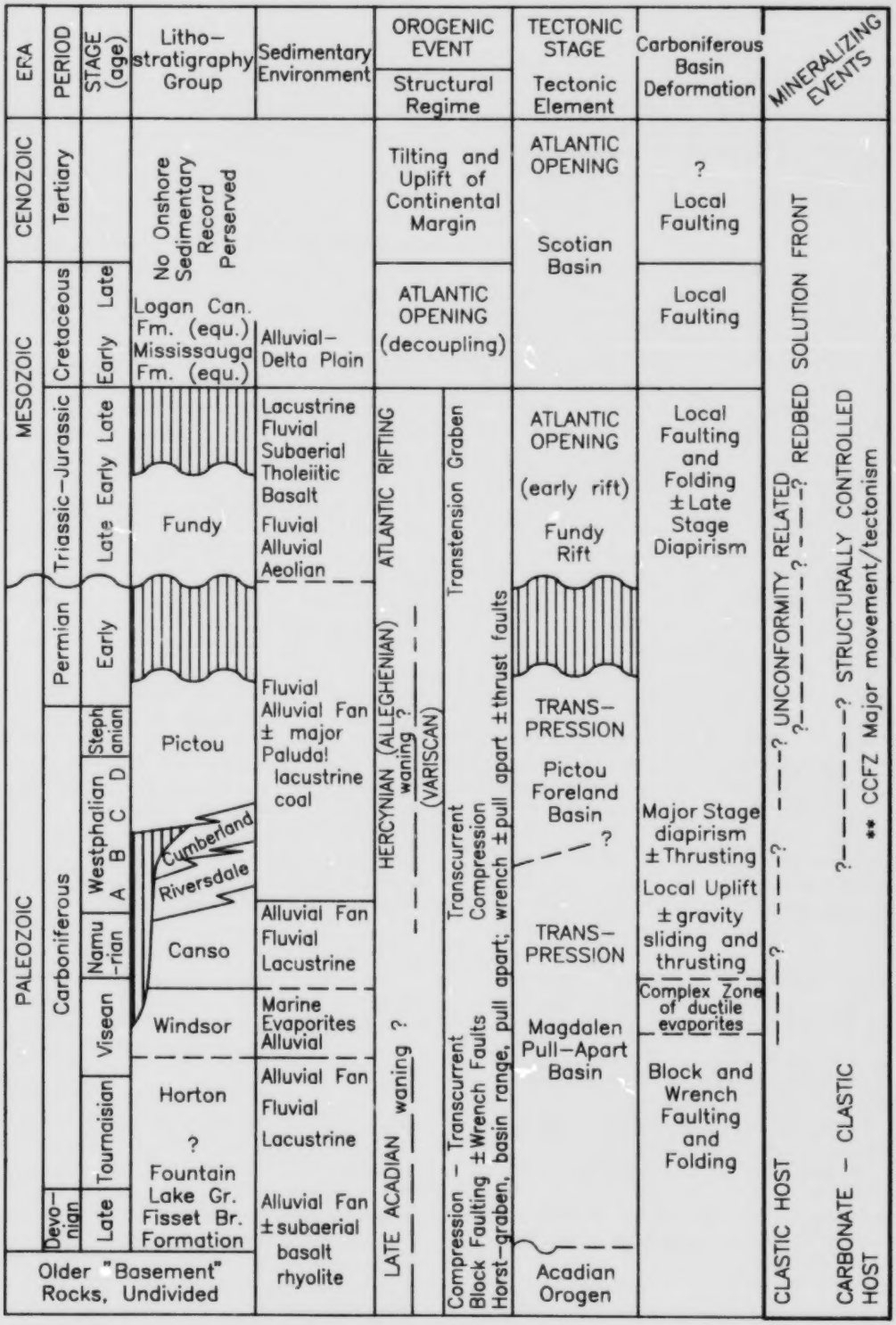

Figure 3. Generalized stratigraphy, tectonics and mineralizing events in Nova Scotia.

reflects the complexity inherent to this tectonically active setting.

LATE DEVONIAN - VISÉAN

The late Devonian to early Viséan was characterized by crustal instability with initial molassic deposition of coarse- to fine-grained alluvial, fluvial and lacustrine sediments, and locally rift-related volcanic deposition in intermontane basins (Fountain Lake Group and Horton Group). These rocks are rarely mineralized except near the contact with the overlying marine evaporitic rocks of the Viséan Windsor Group. A possible exception may be the late Devonian(?) Lochaber Lake copper deposit, which could be interpreted either as synsedimentary or as epigenetic (late Carboniferous?). Rare paleoplacer deposits also occur, such as the gold placer deposit at the unconformity between Horton Group conglomerate and Meguma Group slate near Gays River.

The basin complex was breached in the Viséan by a major evaporitic marine incursion of the sub-sea level landscape (Kirkham, 1978). Nonmetallic mineral deposits are abundant (e.g. limestone, dolomite, anhydrite, salt and secondary gypsum hydrated from anhydrite). Significant potash salts (sylvite and carnallite) were deposited at several stratigraphic levels during periods of extreme restriction and evaporation. Although economic potash deposits have not yet been identified in Nova Scotia, two deposits are currently exploited in New Brunswick.

Syngenetic mineralization appears to be limited to low grade enrichment in Cu, Pb and Zn sulphides, pedogenic-diagenetic Fe and Mn, and locally barite and celestite replacements especially near disconformity redox boundaries between marine carbonates and evaporites or redbeds. The basal Windsor Group carbonate (Macumber Formation) contact with the Horton Group is a locus for numerous occurrences. Syngenetic models for the Gays River Pb-Zn deposit have been questioned and a diagenetic-epigenetic model has been proposed by Akande and Zentilli (1984) and Ravenhurst and Zentilli (1987). The syngenetic-exhalative origin for the Jubilee Pb-Zn deposit recently proposed by Hein et al. (1988) contrasts with earlier structurally controlled-epigenetic interpretations and is not yet clearly established.

NAMURIAN - PERMIAN

In the late Viséan-Namurian the basins returned to continental sedimentation, evolving into a broad, low relief floodplain - lacustrine depocenter (Belt, 1968) dominated by fine grained sedimentation (Canso-Mabou Group). This was succeeded by coarse fluvial braidplain deposition with locally developed alluvial fans in the Westphalian A (Riversdale Group). In the Silver Mine (Yava deposit) area of southeastern Cape Breton Island syngenetic to early diagenetic lead deposits formed in early Westphalian sandstone. These deposits are located at the unconformity where grey sandstone onlaps felsic basement (rhyolite porphyry) at or near the pinchout of evaporitic Windsor and Canso Group strata.

Major lateral (dextral transform) motion along the Cobequid-Chedabucto Fault System culminated in the mid-Westphalian with complex and locally intense deformation with thrusting, especially in southern New Brunswick (Nance, 1987) as well as other areas adjacent to the fault zone.

Tectonic-related epigenetic mineral deposits, in contrast, are numerous and widespread, especially along the Cobequid-Chedabucto Fault System (CCFS). The late Westphalian event involved fault and fold deformation related to dextral motion on the CCFS and its subsidiaries. It coincided with locally rapid uplift and subsidence, and thick sediment accumulation, especially in the Cumberland Basin and the central part of the Maritimes Basin in the Gulf of St. Lawrence. Elevated geothermal gradients probably accompanied the deep seated tectonism, (including plutonism in highland and platform areas) especially in the deeper, rapidly subsiding basins and near the CCFS.

The basins, therefore, experienced optimum conditions for potential hydrothermal mineralizing events. Metalliferous brines, developed deep in the basin fill and constrained by the impermeable Viséan evaporites, were driven toward the basin margin, particularly toward the Meguma Platform to the south (Ravenhurst and Zentilli, 1987). They interacted with reactive host rocks both along escape paths provided by faults and fractures as well as in reservoir-stratigraphic trap settings where physical and chemical conditions were conducive to mineral precipitation and replacement. The basal Windsor Group carbonate was a primary host and deposit examples may include Gays River, Smithfield, Upper Brookfield, Pembroke, Middle Stewiacke, Walton and vicinity, and Jubilee. This Westphalian event may be the most significant with respect to metallogenesis in the Late Paleozoic basins in Nova Scotia.

Fracture-fill vein mineralization is locally hosted in pre-Carboniferous basement rocks and

may be related to this event. Examples include vein barite along the CCFS on the south side of the Cobequid Highlands and some of the barite-fluorite veins near Lake Ainslie. These deposits may be compared with the structurally controlled Pb, Zn, F, Ba and Cu mineralization of the Pennines in Carboniferous basins of central Great Britain (Dunham, 1978). The British comparison is limited, however: Viséan sediments are not as evaporitic, the Namurian is characterized by more competent sandstone facies and the deposit mineralogy tends toward carbonate assemblages as opposed to Nova Scotia's abundant sulphates, mudrock-dominated Namurian and evaporite-dominated Viséan.

The late Permian in Nova Scotia was dominated by a major hiatus coincident with an important reddening episode in late Carboniferous strata, especially in the Cumberland Basin. This reddening, associated with low water tables, generated numerous solution-roll front mineralizing settings represented by Cu, Ag and locally U mineral occurrences.

MESOZOIC - CENOZOIC

During the late Triassic to early Jurassic, continental rift sedimentation occurred in the area of the CCFS. Alluvial, fluvial and lacustrine redbeds and tholeiitic basalt (locally with minor native Cu) were deposited and preserved in narrow graben to half graben basins in the Bay of Fundy (Fundy Rift) and Chedabucto Bay (Orpheus Graben). These basins represent early stage rifting related to sinistral motion on CCFS during Proto-Atlantic development and rest with profound unconformity on the eroded late Paleozoic landscape. The distribution of pre-Cretaceous material beyond the rift areas is unknown but may have been extensive and potentially covered most of Nova Scotia except for the highest uplands.

Similar early Mesozoic sedimentation in a rift valley setting occurred offshore but included evaporites and lacked widespread volcanics. Although mid to late Jurassic sediments are not preserved onshore, they are present in the Scotian Basin as marine transgressive facies and may have extended onshore. Uplift-tilting with erosion may have occurred onshore at this time. The only preserved late Mesozoic sedimentation onshore is recorded by unconsolidated, interstratified silica sands, kaolinitic clay and mud with minor lignite of early Cretaceous age. These sediments rest on the eroded late Paleozoic landscape unconformity and the preserved distribution is probably minor in comparison to the pre-erosional extent. The early Cretaceous sediments probably represent terrestrial fluvial-alluvial plain to coastal(?) plain equivalents of the extensive prograding deltaic-marine facies in the Scotian Basin. They generally record deposition as an accretionary prism along the subsiding shelf and continental margin of the opening Atlantic Ocean. No preserved sedimentary record occurs onshore for the late Cretaceous to Tertiary.

CONCLUSIONS

Late Paleozoic mineral deposits may be divided into two main genetic affinities: (1) related to sedimentary and near surface groundwater processes, and (2) related to large-scale basin tectonics and diagenetic fluid migration within basins. The sandstone-hosted deposits and rare paleoplacers are closely related to unconformities (depositional hiatus), paleoclimate, groundwater, weathering and sedimentological processes. The diagenetic-syngenetic stratabound deposits occur locally in the early Westphalian (Yava) but more commonly as redox redbed solution fronts in: (1) late Tournasian-early Viséan rocks, especially near the Horton-Windsor Group contact, and (2) in late Westphalian to Stephanian strata (Tatamagouche).

Carbonate-hosted discordant occurrences and deposits are most numerous and widely distributed in the pre-Westphalian basin fill (Gays River, Walton and Scotsville) and are especially common near the basal carbonate of the Windsor Group. Although genetic interpretations of various authors are not always consistent, data compiled from numerous reports describing discordant mineral deposits in Late Paleozoic basins indicate a close spatial and probably temporal relationship with mid-Carboniferous tectonism. Many of the more significant occurrences and deposits are discordant to stratabound, carbonate-hosted (replacement and space fill), at or near the base of the Windsor Group (Macumber or Gays River Formation) or are hosted within pre-early Westphalian basin fill (and locally basement?) within or near the Cobequid-Chedabucto Fault System and its subsidiaries. They have general characteristics compatible with, but not exclusively indicative of, classification as diagenetic-epigenetic. The major source of mineralizing fluids, furthermore, is consistent with derivation within the basin system during a mid-Westphalian tectonic episode and accompanying elevated geothermal gradients. Earlier synsedimentary exhalative origins during the Viséan, however, cannot be eliminated using the available data. The influence of extra-basinal hydrothermal fluids has not been established and perhaps may be significant, especially in the vicinity of the deep seated Cobequid-Chedabucto Fault System. The potential extent of earlier and/

or contemporaneous exhalative phases may have been rendered unrecognizable by tectonic disruption.

The mineral assemblages and mineralization styles are diverse and relatively distinctive, perhaps giving the illusion that they are genetically unrelated. When considered at a basinal scale, however, this variance may be analogous to the variations in similarly complex but genetically inter-related mineral deposits described by Dunham (1978) in Carboniferous basins in Great Britain (e.g. Pennines). The variations in mineralizing style and mineral assemblages generally reflect: (1) contrasts in basin fill competency and permeability and subsequent related fracturing and fluid flow patterns and (2) the complex and evolving mineralizing fluid system in general and the interaction with local physio-chemical conditions at the mineralized sites in particular.

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GOLD IN TILL IN THE ANTIGONISH HIGHLANDS REGION[1]

R. R. Stea

INTRODUCTION

The Antigonish Highlands region has been examined by a till geochemistry survey during the 1984-1989 Canada - Nova Scotia Mineral Development Agreement. The till survey results have been published as Report of Activities submissions, Open File Maps and in an external journal (Turner and Stea, 1987a, 1987b, 1988a, 1988b, 1989a, 1989b, in press).

Many elements were analyzed during the till survey, with the notable exception of gold. The rationale for excluding gold in this survey was as follows: (1) Not enough heavy minerals were obtained from the average till sample (2-4 kg) to warrant analysis of this fraction. (Need 10-20 g of heavy mineral concentrate for fire assay; neutron activation results are spoiled by heavy liquids.) (2) The clay fraction (-2 μm) was believed to be too fine to harbour gold of appreciable quantity because of the low natural abundances of gold and its purported immobility in the secondary environment. (3) Glacial dispersal of gold from deposits in the Meguma terrane is less than 1 km (DiLabio, 1982; MacEachern and Stea, 1985). The sample spacing in the till survey is, on average, about one sample per 13 km^2.

Despite this reasoning, it was decided to analyze the 1986 clay fraction powders for gold. The results are presented in this report, which is a preliminary look at the till survey from a regional perspective. Sample locations and complete analytical results can be obtained from the Open File Maps (Turner and Stea, 1987a, 1987b, 1988a, 1988b, 1989a, 1989b) and consultation with the author.

GENERAL GEOLOGY AND MINERAL OCCURRENCES

The Antigonish Highlands region has a complex geology comprising predominantly Precambrian metavolcanics and metasediments, unconformably overlain by lower Paleozoic strata (Murphy, 1984). East and south of the Antigonish Highlands Devonian-Carboniferous evaporitic and clastic sedimentary rocks predominate in the Antigonish-Guysborough Lowlands (Fig. 1).

Several stratiform Cu-Pb-Zn mineral occurrences (Ohio-Sylvan Glen copper belt) are located at the contact between Windsor Group carbonates and Horton Group conglomerates (Fig. 1; Bourque, 1981; Chatterjee, 1983). Copper minerals include malachite, chalcopyrite, chalcocite and/or bornite and azurite. Lead and zinc occur as galena and sphalerite. To the west an unconformity separates Windsor Group carbonates and Keppoch Formation metavolcanics. The Cross Roads Ohio Cu-Pb-Zn-Ag occurrence is hosted by a rhyolitic lithic tuff of the Keppoch Formation (Fig. 1). Mineralization occurs as fracture fillings in a secondary breccia stockwork. No silver minerals have been identified but Ag values are reported at 0.5 oz./ton (K. Northcote, personal communication, 1987). Fletcher (1886) reported that gold had been mined in the region. Northcote et al. (1989), however, failed to confirm high gold values although they obtained anomalous assays (20 ppb). Murphy (1984) identified small, stratabound pyritic zones (with traces of copper minerals) occurring within the rhyolitic tuffaceous volcanic member of the Keppoch Formation. Northcote et al. (1989) reported erratic gold values (up to 30 ppb) in one of the pyritic zones east of the Cross Roads Ohio occurrence.

A gold occurrence has been reported in the Hadrynian Keppoch Formation along a major northwesterly-trending fault in the western highlands (Murphy, 1986) (Fig. 1). Some gold anomalies were obtained from stream silts in the region (Mann, 1986). Northcote et al. (1989) assayed some of the wall rock and vein material at the site but failed to detect gold.

QUATERNARY GEOLOGY

Striations, till fabric, glacial landform analysis, and

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

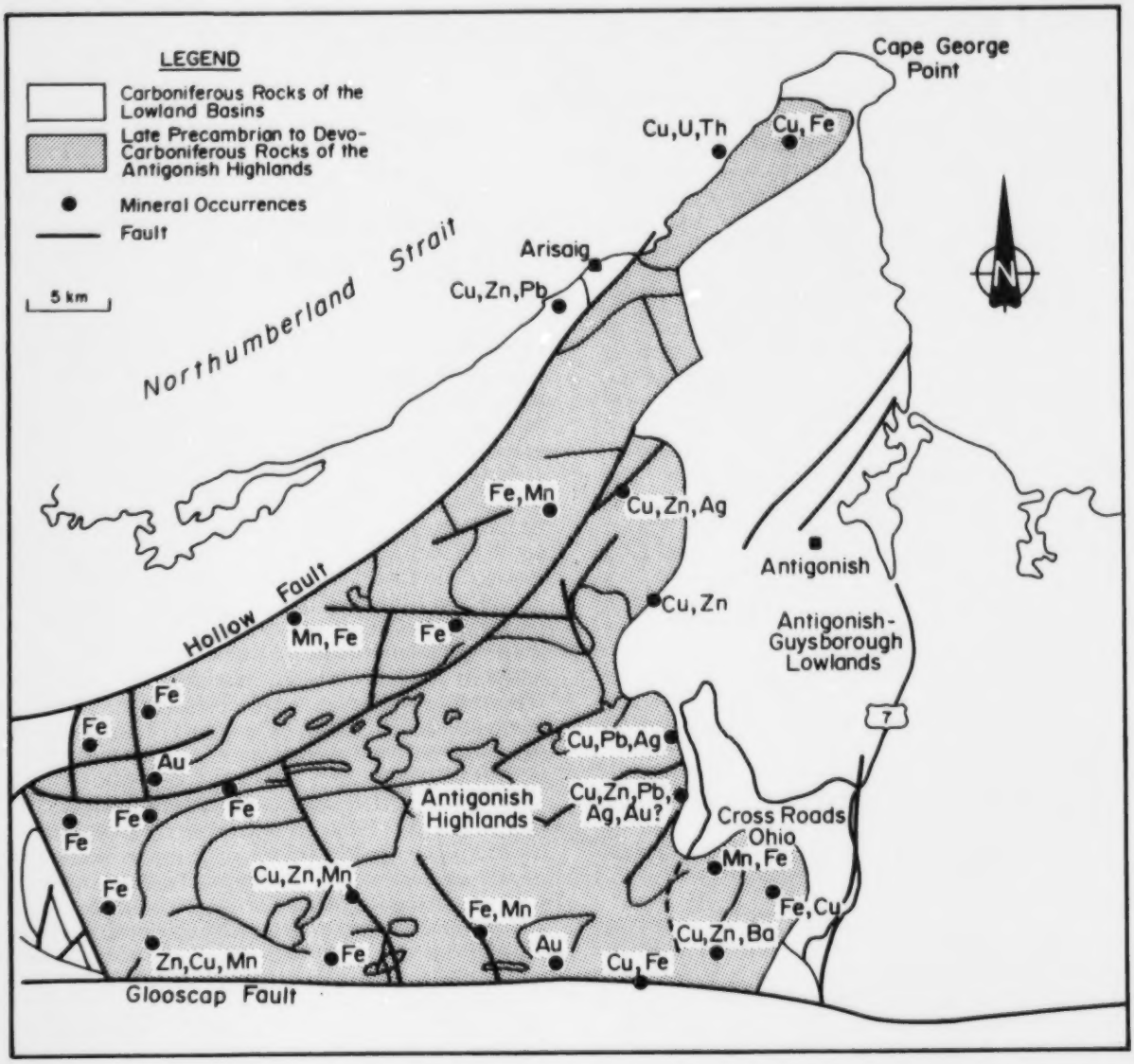

Figure 1. Simplified geology, mineral occurrences and faults in the Antigonish Highlands region.

the dispersal of distinctive erratics indicate that the northern mainland of Nova Scotia has been affected by at least four major ice flows with some local piedmont and valley glaciers (Stea and Finck, 1984; Stea, 1984). An Early Wisconsinan (?) eastward to southeastward ice flow produced a thick, indurated, matrix-dominated till (McCarron Brook Till) that subcrops beneath surface tills along the Northumberland Strait coast. Its presence elsewhere beneath the surface till is conjectural.

Two major surface till units were sampled in the till survey. They were formed by two separate phases of ice flow. In much of the lowland region a surface till sheet called the Eatonville Till overlies the McCarron Brook Till (Stea et al., 1986). The Eatonville Till is characterized by a red silty matrix and a pebble fraction derived largely from Carboniferous sedimentary rocks. Stony, locally-derived tills overlie the Eatonville Till. Late-stage glaciers flowed southwestward from the Antigonish Highlands and sporadically deposited these stony tills.

SAMPLING AND ANALYTICAL METHODS

Sampling and sample preparation methods for the

till survey have been described in detail in Stea et al. (1986) and Turner and Stea (1988a, 1988b, 1989a, 1989b). The fine fraction of the till sample (<0.002 mm) used in the Au analysis was separated by a two-stage centrifuge process. This process eliminates contamination inherent in screens through re-use. Gold was analyzed by fire-assay Atomic Absorption Spectroscopy (AAS).

ANALYTICAL VARIATION

In the till survey duplicate powders and control samples were randomly inserted into each batch of 20 samples sent to the lab. Table 1 shows the results of the duplicate analyses. Most of the samples fall below the detection limit of 2.5 ppb and of the 6 duplicate pairs yielding values > 2.5 ppb only 2 were replicated. The remaining 4 pairs ranged from detection limit to 14 ppb. This suggests that gold values from detection limit to 15 ppb are not significant, and isolated samples with gold levels in this range should be considered as background unless verified by better duplicate data. The control sample generated values ranging from 100-600 ppb.

Table 1. Gold duplicate analyses from batches of 20 till samples from 1986 sampling year.

Number	Sample Value	Duplicate Value
1	2.50	2.50
2	2.50	10.00
3	14.00	2.50
4	2.50	2.50
5	2.50	13.00
6	2.50	2.50
7	7.00	2.50
8	2.50	9.00
9	9.00	17.00
10	2.50	2.50
11	2.50	2.50
12	2.50	2.50
13	9.00	10.00
14	2.50	2.50
15	2.50	2.50
16	2.50	2.50
17	2.50	2.50
18	2.50	8.00
19	2.50	2.50
20	2.50	2.50
21	2.50	2.50
22	2.50	2.50

RESULTS

The till results are shown in Figure 2. This figure is a combined contour and proportional symbol plot. The symbols are proportionally larger with higher gold values. The contouring method involves a weighted average of 6 nearby data points and therefore represents a 'trend surface'. The contours do not honour all control points represented by the proportional symbols. This contouring method decreases the effect of isolated 'anomalies' in favor of larger areas characterised by consistently elevated numbers.

Gold levels in the till show a strong background population with a distinct 'tail' of elevated values (Fig. 2). The till plot shows a linear, northwesterly-trending anomalous zone that extends along the contact of the highland rocks with Antigonish Basin right through to the Northumberland Strait shore. A belt of anomalies also extends in a northeastward direction from Arisaig to Cape George Point. There are coincident stream geochemical anomalies in the same belt (R. F. Mills, personal communication, 1989). The clustering of elevated values strongly suggests that the values are significant. This does not imply that the values reflect economic mineralization, rather that they are not a result of random sampling or analytical error.

The till survey shows a marked 'bullseye' of anomalies (Fig. 2) in the Cross Roads Ohio area. In a recent stream sediment survey, the highest fine fraction value (2400 ppb) was recorded in a sample taken within 2 km of Cross Roads Ohio (R. F. Mills, personal communication, 1989). Curiously, a heavy mineral concentrate of the same stream sample was barren of gold. Several till samples in the region have gold values greater than 40 ppb.

DISCUSSION AND CONCLUSIONS

Gold values in the till delineate an anomalous zone in the Antigonish Highlands parallel to the Ohio-Sylvan Glen copper belt. The anomalies, however, extend past the known occurrences into the lowlands north of the Hollow Fault. In the till data set, Au is significantly correlated with Cu, Pb, Co, Mn, U and Mo. These elements are all common to minerals found in the occurrences in this belt. This evidence strongly suggests a link between the mineral deposits and the gold anomalies. Northcote et al. (1989) obtained gold values generally in the range of 10-30 ppb from pyritic belts related to the mineral deposits. Till anomalies in the region are generally in the 15-40 ppb range.

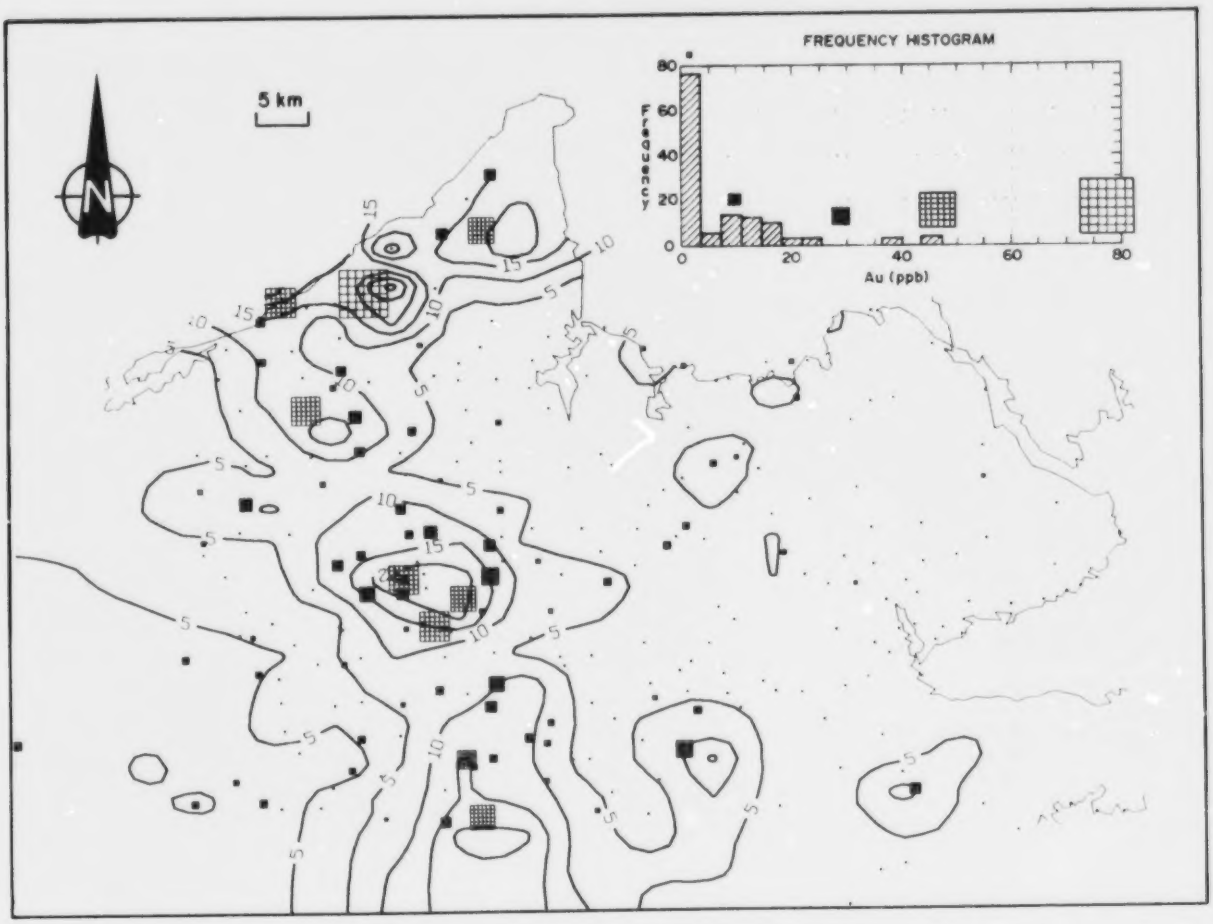

Figure 2. Contour - proportional plot of gold levels in till, Antigonish Highlands region.

The till fine fraction plot defines a much broader area of elevated values than the area of the mineral deposits. Some of this effect may be attributed to glacial dispersal, but the area of anomalies is too large to be caused by dispersal from one or two sources. This suggests potential for undiscovered gold showings or base metal occurrences rich in gold.

Northcote et al. (1989) conclude that most of the mineral deposits in this belt have strong secondary brecciation that hosts the mineralization. They suggest fault-related hydrothermal activity as a possible origin. The northwest trend of gold anomalies and the copper belt may be significant, perhaps relating to a cryptic northwest-trending fault structure. A gold occurrence is located along one of these faults (Chatterjee, 1983). Wright et al. (1988) suggest a relationship between late sulphide mineralization and northwest-trending faults in the Meguma Zone. Hudgins (personal communication, 1989) suggests that gold anomalies in the Carboniferous basins of New Brunswick may be epithermal, related to a late mineralizing event.

The majority of till anomalies are in the clay fraction. This suggests that nuggets are not responsible for the anomalous values, but rather extremely fine grained gold contained within sulphide minerals and/or gold released from gangue by weathering are the sources of these values. Some of the higher numbers may therefore represent 'false' anomalies enhanced through some form of co-precipitation or adsorption process. The results are of sufficient interest, however, to warrant more detailed study of the anomalous areas, especially along the Ohio-Sylvan Glen copper belt and in the lowlands north of Hollow Fault.

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PROGRESS REPORT ON THE QUATERNARY GEOLOGY MAP OF NOVA SCOTIA[1]

R. R. Stea

The Quaternary map of Nova Scotia is a compilation from all available maps of the glacial and surficial geology of the Province. The map will feature the distribution of glacial deposits such as tills, drumlins, eskers and outwash, areas of bedrock exposure and the distribution of recent peatlands, salt marshes, beaches and flood plains. Included with the map will be informative graphics describing the stratigraphy of the glacial deposits and patterns of ice advances and retreats. All known radiocarbon dated localities will be compiled on the map as will stratigraphic sections of special interest. The map is being compiled at a scale of 1:250 000, and will be presented at a 1:500 000 scale. The end product will be a 1:500 000 scale colour map and digital files with surficial information.

The map is now 85% complete, with the surficial units and symbols compiled on matte overlays. The legend and radiocarbon locality compilation have yet to be completed. After checking, these maps will be ready for drafting. Maritime Resource Management Service in Amherst, Nova Scotia, will be drafting and digitizing the surficial information and preparing printer's negatives for the final map.

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

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TERRANES IN NOVA SCOTIA: THEIR CHARACTERISTICS AND ACCRETIONARY HISTORY[1]

J. D. Keppie, J. B. Murphy[2], R. D. Nance[3], J. Dostal[4]

Nova Scotia is divisible into two terranes, Avalon and Meguma terranes, separated by the Minas Fault System. The Avalon Composite terrane is defined by the presence of a lithostratigraphically correlative, subaerial-shallow marine, Cambro-Ordovician overstep sequence containing an Acado-Baltic fauna (Keppie, 1985). In general, these Cambro-Ordovician rocks are only preserved in outliers, so overstep relationships are inferred from their close lithostratigraphic similarity. Where the Cambro-Ordovician rocks have been removed by erosion, it is possible to use the presence of the lithostratigraphically correlative, Siluran-Gedinnian overstep sequence containing the distinctive Rhenish-Bohemian fauna (Boucot, 1975). By this definition, the Avalon Composite terrane includes most, if not all of northern Nova Scotia (Figs. 1-4). In these areas, the Early Paleozoic rocks rest unconformably-disconformably-conformably upon a variety of Late Precambrian volcanic rocks and turbidites overlying Middle/Late Proterozoic or older metasediments and gneisses. Contrasts in the Precambrian stratigraphy led to the subdivision of the Avalon Composite terrane into several Late Proterozoic terranes (Keppie, 1985, 1988). The main terranes were: (a) Cape Breton terrane: a cratonic magmatic arc; (b) Antigonish Highlands and Cheticamp terranes: inter-arc basins floored by oceanic lithosphere; and (c) Cobequid Highlands terrane: a cratonic magmatic arc. However, new data have allowed lithostratigraphic correlations to be made across northern Nova Scotia which suggest the presence of just one terrane consisting of alternating basins floored by thinned continental lithosphere (rather than oceanic lithosphere) and horsts (Keppie et al., in press). These are interpreted as a magmatic arc - intra-arc rift complex that lacks oceanic components, which formed above a northeasterly-dipping subduction zone (Dostal et al., in press).

In contrast, Barr and Raeside (1986) have

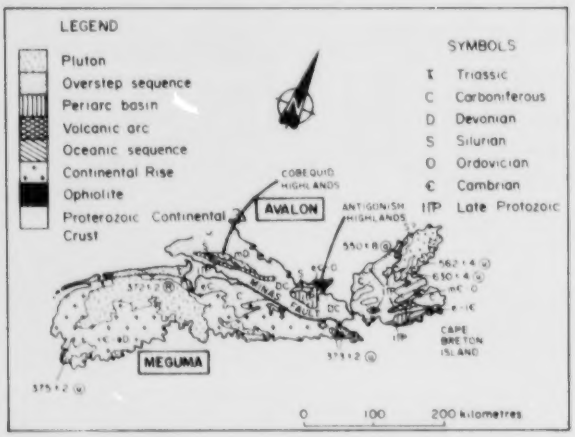

Figure 1a. Tectonic map of Nova Scotia showing two terranes (Avalon and Meguma) separated by the Minas Fault.

subdivided Cape Breton into four tectonostratigraphic zones or terranes, designated from southeast to northwest: Southeastern Bras d'Or, Highlands and Northwestern Highlands. They define these terranes as follows: (1) Southeastern terrane: late Precambrian volcanism and plutonism followed by Cambro-Ordovician rift basin sedimentation and minor volcanism; (2) Bras d'Or terrane: gneissic basement overlain by platformal sedimentary rocks (Georges River Group) intruded by mainly late Precambrian and Ordovician(?) granitoid rocks; (3) Highlands terrane: gneissic core flanked by low grade sedimentary and volcanic rocks of probable Precambrian age intruded by diverse Precambrian-Carboniferous plutons: and (4) Northwestern highlands terrane: gneissic basement intruded by varied plutonic rocks including anorthosite and Grenvillian syenite. Subsequently, Raeside (1987) split the Highlands terrane into the Aspy and Ingonish terranes and then incorporated the Ingonish terrane within the Bras d'Or terrane (Loncarevic et al., 1989). Barr and Raeside (1986)

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1 Also published in International Geological Correlation Programme, Project #233 Annual Meeting, Abstracts with Program, p. 51-57.

2 Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia B2G 1C0
3 Department of Geological Sciences, Ohio University, Athens, Ohio, U.S.A. 45701
4 Department of Geology, St. Mary's University, Halifax, Nova Scotia B3H 3C3

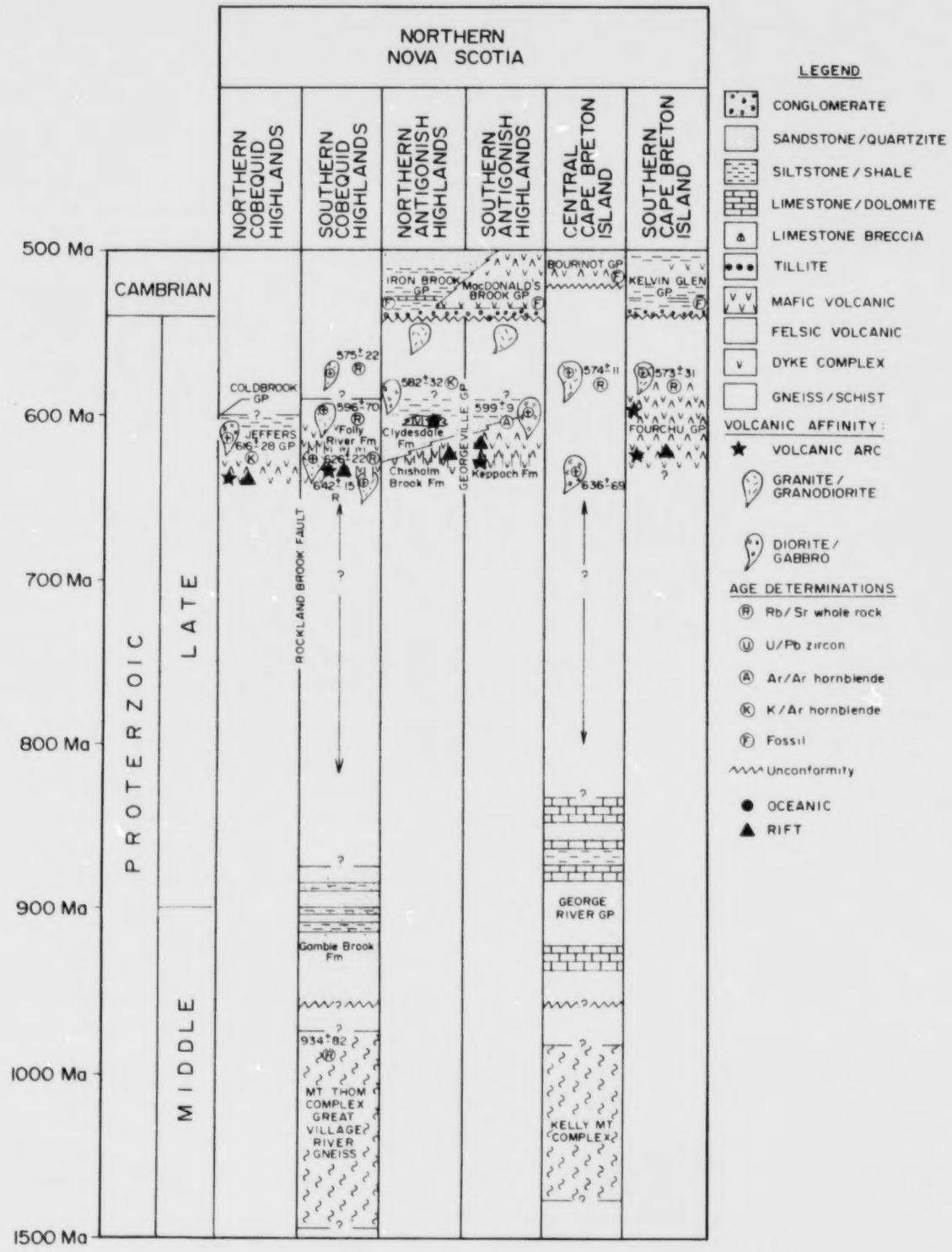

Figure 1b. Correlation chart for the Avalon terrane.

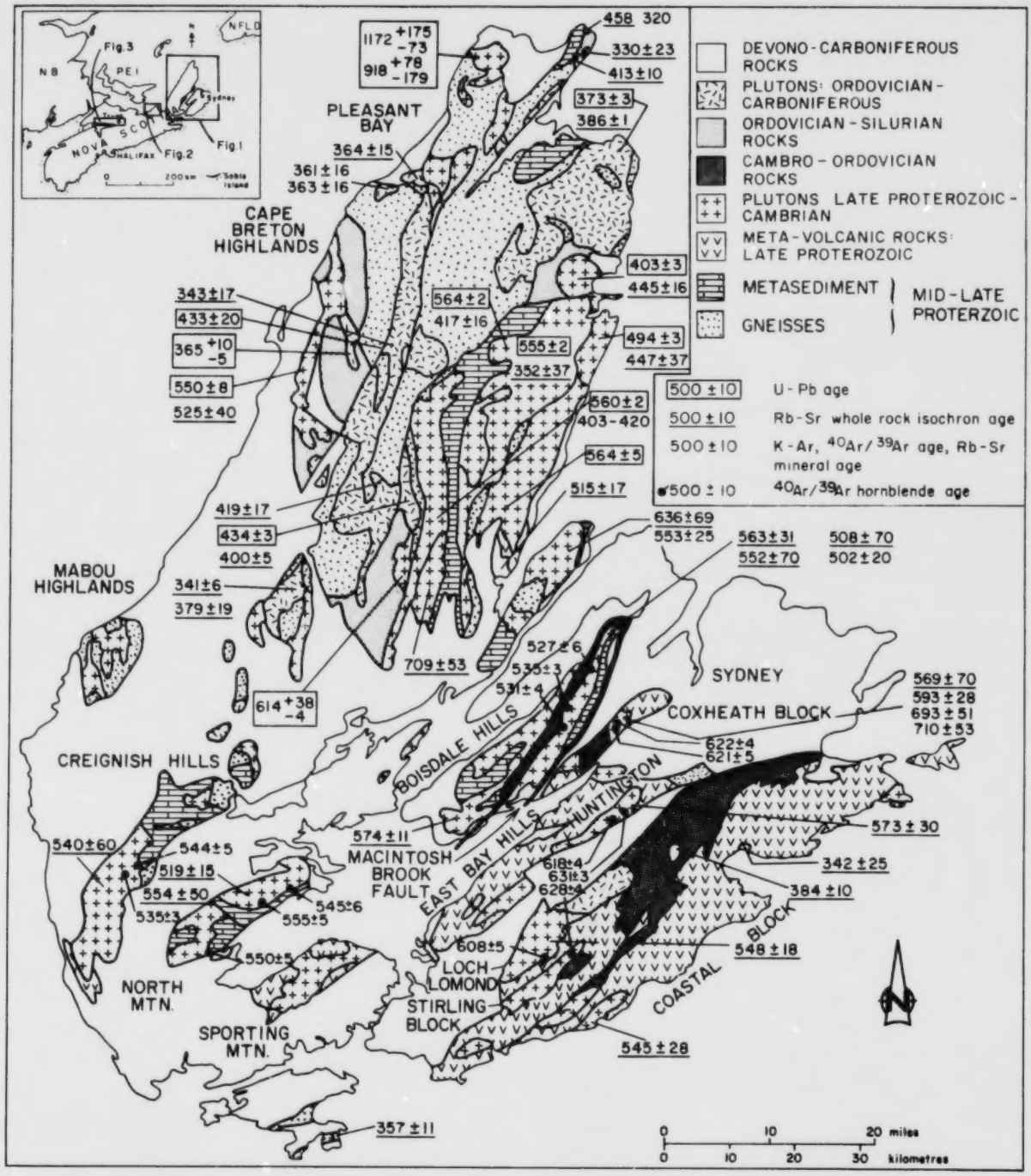

Figure 2. Geological map of Cape Breton Island.

inferred that the Southeastern and Bras d'Or terranes are part of the Avalon terrane, although Barr et al. (1987) correlated the Bras d'Or terrane with the Gander terrane. The Aspy/Highlands terrane correlated with the Gander terrane or outboard edge of the Piedmont terrane in Newfoundland, and the Northwestern Highlands terrane was inferred to be an outboard part of autochthonous, Grenvillian North America (Piedmont terrane of Williams and Hatcher, 1983; North American terrane of Keppie, 1988). However, other data suggest that Cape Breton Island, like northern mainland Nova Scotia, represents a single Avalonian terrane (Fig. 2). Keppie (1979, 1982) and Currie (1987) have shown that the felsic and mafic gneisses in the Northwestern Highlands "terrane" may be traced through both the Aspy/Highlands and Bras d'Or "terrane". In addition, the Precambrian platformal unit characterized by the George River Group (Keppie, 1979) in the Bras d'Or "terrane" may be traced into the Aspy/Highlands "terrane" as the McMillan Flowage Formation (of Barr and Raeside, 1986) and Cape North Group (of MacDonald and Smith, 1980). Also, late Proterozoic volcanic rocks and the Cambro-Ordovician overstep sequence are present in both Southeastern and Bras d'Or "terranes". Recently, pebbles containing Cambro-Ordovician and Silurian fauna typical of the Avalon composite terrane have been found in a Lower Carboniferous conglomerate derived from the Mabou Highlands (Keppie et al., in press) lying within the Aspy/Highlands "terrane". Furthermore, published geochronological data show that Late Proterozoic - Cambrian and Paleozoic plutons are present across most of Cape Breton Island. The basement beneath the Southeastern "terrane" is not exposed, however, the geochemistry of the Late Proterozoic volcanic rocks indicates the presence of continental crust (Keppie et al., 1979; Dostal et al., in press). Thus, these data suggest that the rocks of Cape Breton Island, rather than representing an entire cross section of the Appalachian Orogen and distinct terranes as proposed by Barr and Raeside (1986), expose an oblique section of the Avalon composite terrane with progressively deeper levels of the late Proterozoic magmatic arc complex cropping out north-westwards. That the gneisses in northern Cape Breton Island are not contiguous with the outer edge of cratonic North American basement is indicated on seismic reflection profiles between Newfoundland and Cape Breton Island which show the top of the Grenvillian basement at a depth of >10 seconds two-way travel time in the Cabot Strait off northern Cape Breton island (Marillier et al., in press).

The Meguma terrane is the farthest outboard

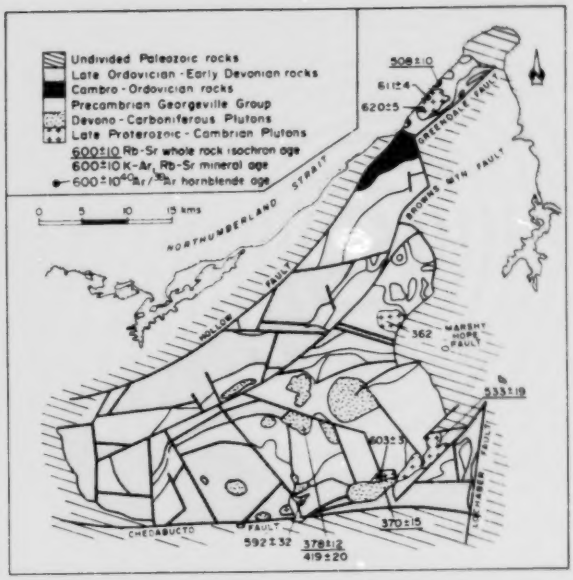

Figure 3. Geological map of the Antigonish Highlands.

terrane in the northern Appalachians where it is juxtaposed against the Avalon terrane (Keppie, 1985, 1989). It is characterized by thick (?) Cambro-Ordovician turbidites of the Meguma Group (Schenk, 1970) overlain by shallow marine and continental rocks. The Meguma Group is made up of two formations: Goldenville and Halifax Formations. The >5500 m thick Goldenville Formation is made up mainly of metawackes with thin slate interbeds. It is overlain by 500-4000 m thick Halifax Formation, which is predominantly slate with subordinate siltstone and wacke. The basal Halifax Formation contains Tremadocian grapolites, but no fossils with an unique age assignment have been recovered from the Goldenville Formation. In contrast, the Lower Paleozoic rocks of the neighbouring Avalon terrane are typically platformal rocks containing a *Paradoxides* Cambrian trilobite fauna (Hutchinson, 1956; Palmer, 1973) and a *Selenopeltis/Trinucleid* Ordovician trilobite fauna (Whittington, 1973).

Docking of the Meguma and Avalon terranes was recorded by regional folding, cleavage development and concomitant low grade metamorphism, which has yielded $^{40}Ar/^{39}Ar$ whole rock phyllite ages ranging from circa 400-377 Ma (Keppie and Dallmeyer, 1987). Subsequent accretionary telescoping between the Meguma and Avalon terranes was recorded by dextral shear zones with $^{40}Ar/^{39}Ar$ mica plateau ages ranging from circa 375-287 Ma (Dallmeyer and Keppie, 1987). This was synchronous with granitoid

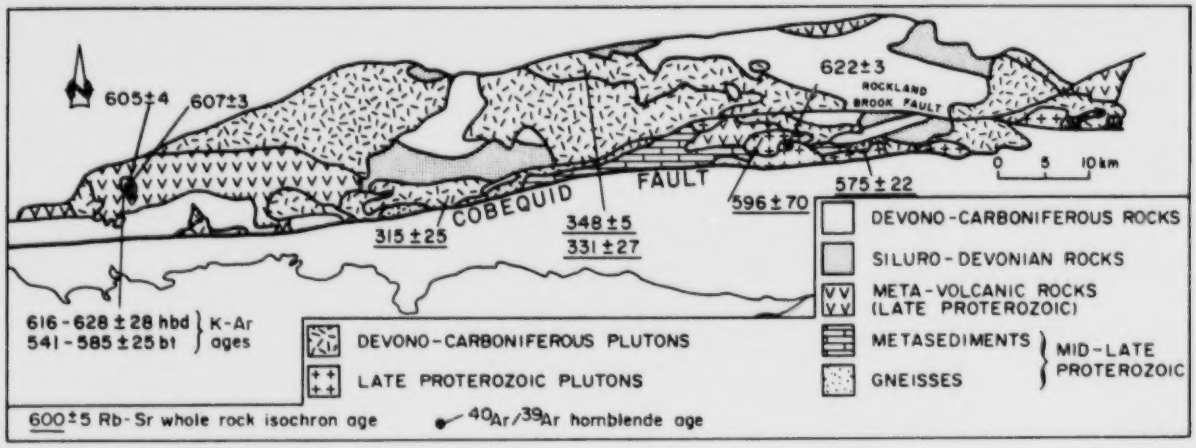

Figure 4. Geological map of the Cobequid Highlands.

plutonism ranging in age from circa 375-270 Ma (Clark and Halliday, 1980; Keppie et al., 1985; Cormier et al., 1987), and the deposition of Carboniferous strata as an overstep sequence across the Meguma-Avalon terrane boundary which were also involved in the Late Paleozoic deformation. The proximity of the Meguma and Avalon terranes in Late Silurian/Early Devonian times is signalled by the appearance of Rhenish-Bohemian brachiopod fauna on both terranes in Pridolian rocks, which spread northwards in to the Gaspé Peninsula by Emsian times where they are mixed with Eastern Americas Realm taxa (Boucot, 1975). The closure of the ocean between Euramerica and Gondwana by Late Devonian was followed by the dispersal of fresh water vertebrates across the entire region by this time (Young, 1981).

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ACTIVITIES OF THE EDUCATION AND PUBLIC AWARENESS GROUP[1]

H. V. Donohoe, Jr.

IMPORTANCE OF EDUCATION AND PUBLIC AWARENESS

Increased knowledge of Nova Scotia's mineral resources, geology and mineral industry allows a broader understanding of their importance and influence in everyday life and future planning. The Education and Public Awareness Group works closely with many groups, government agencies and individuals to foster this understanding and appreciation.

Mandate

The mandate of the Education and Public Awareness Program is to describe, interpret and promote the mineral resources, geology and mineral industry of Nova Scotia and to publicize the role and work of the Department of Mines and Energy.

Objectives

In fulfilling its mandate, the Education and Public Awareness Group develops its program to accomplish the following objectives:
(1) Provide information about the mineral resources, geology and mineral industry in Nova Scotia to a wide variety of people, institutions, and government agencies;
(2) Develop an understanding of the importance of the mineral industry in Nova Scotia;
(3) Promote the understanding and use of geological and mineral resource information for mineral exploration, land use planning, and government activities;
(4) Assist teachers and students in schools and universities in obtaining information about Nova Scotia's mineral industry, geology and mineral industry; and
(5) Help residents and visitors appreciate the variety of geological features and mining heritage in the Province and promote these as destination points.

METHODS OF PRESENTATION

The Education and Public Awareness Group uses a variety of methods in developing the objectives of the program. Lectures, seminars, interpretive walks and courses are examples of direct contact methods. Displays are used with and without staff of the program. Publications are available at displays, the Department of Mines and Energy Library and the Nova Scotia Government Bookstore.

ACCOMPLISHMENTS DURING 1989

A wide variety of educational and public awareness activities were presented during 1989 by the staff of the program. One of the major accomplishments was completion of the *Geological Highway Map of Nova Scotia*, Revised Edition, which was a co-operative project between the Atlantic Geoscience Society, the Nova Scotia Museum and the Department of Mines and Energy. Seminars, walking tours, and short courses and talks described and interpreted the geology of the Province and the importance of its mineral industry.

Displays

Displays prepared by the Education and Public Awareness Group provided information about the Province's mineral resources and mineral potential, geology, mineral industry, and the role of the Department. Over 45,000 people attended the events, shown in Table 1, for which displays were prepared. The technical displays provided detailed information about the mineral resources of the Province, promoted the mineral industry and the potential for mineral development and demonstrated new methods for mineral exploration. Non-technical displays described the Department and its work, promoted the mineral industry and provided information about the geology and mineral resources of the Province.

Walking Tours

Seventeen walking tours were presented in various parts of the Province. Their dates, locations and subjects are shown in Table 2. More than 300 people attended these walks. The

1 Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

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Table 1. 1989 Public Information Program displays.

Date	Location	Event
March 5 - 8	Toronto	Prospectors and Developers Association of Canada
June 9 - 11	Windsor	Nova Scotia Forestry Exhibition
Aug. 11 - 13	Parrsboro	Rockhound Roundup
Oct. 12 - 15	Halifax	Atlantic Winter Fair
Oct. 20, 21	Musquodoboit Harbour	Eastern Shore Development Commission

Table 2. 1989 Public Information Program geological walks.

Date	Location	Walk
May 4	Halifax	Geology of Point Pleasant Park
May 17	Peggys Cove	Geology of Peggys Cove*
May 28	Halifax	Building stones of Spring Garden Road
May 30	Truro	Building stones of Prince Street
June 4	Truro	Geology of Victoria Park
June 6	Halifax	Geology of Point Pleasant Park
June 13	Dartmouth	Geology of the Dartmouth Commons
June 20	Halifax	Building stones of downtown Halifax
June 27	Peggys Cove	Geology of Peggys Cove
July 4	Halifax	Building stones of Spring Garden Road
July 16	Halifax	Geology of Point Pleasant Park
July 18	Truro	Geology of Victoria Park
July 25	Dartmouth	Geology of the Dartmouth Commons
August 8	Halifax	Building stones of downtown Halifax
August 12	Five Islands	Geology of Five Islands Prov. Park*
August 15	Peggys Cove	Geology of Peggys Cove*
August 22	Truro	Building stones of Prince Street

*These walking tours were also part of the Nova Scotia Department of Lands and Forests *Parks are for People Program*.

Education and Public Awareness Group participated in the Nova Scotia Department of Lands and Forests *Parks are for People Program* with three walking tours of provincial parks. Walking tours are a useful method of interacting directly with an audience to describe important parts of the program's objectives.

Publications

The completion and publication of the *Geological Highway Map of Nova Scotia*, Revised Edition, marked an important contribution for educational programs and visitor/resident information and destination promotions. The map

is designed to be understood by non-geologists who are interested in the natural history of the Province. At the same time the map has enough information to be used by geological students and professionals. The use of specific site information enables users to locate destinations of interest for visiting. The map shows the distributions of rocks, locations of producing mines and quarries and former mines, sites of interest for collecting rocks, minerals and fossils and studying landforms, and an informative geological history of the Province.

A publication about careers in geology was completed during 1989 as part of a co-operative project between the Atlantic Provinces Council on the Sciences (APICS) Geology Committee and the Department. The brochure will be used as an information source for students in high school and university and high school guidance counsellors.

Education

The Education and Public Awareness Group presented a wide range of lectures,talks, field trips and seminars during 1989. Table 3 shows the variety of presentations and the target audience. The Department, through the Education and Public Awareness Group, is continuing its co-operative project with the Nova Scotia Museum to complete *The Mining Kit*, a museum loan kit for junior high school science classes in Nova Scotia. The kit contains a Teachers' Guide, videos, rock and mineral samples, slides of mineral production sites and a wealth of printed material, including the revised *Geological Highway Map of Nova Scotia*.

SUMMARY

The variety of activities of the Education and Public Awareness Group allows a large number of people to learn more about the mineral resources, geology and mineral industry in Nova Scotia. Visitors and residents are made more aware of specific travel destination points based on the geology, fossils and minerals of the Province. All of this work provides a stronger, more positive public image of the Department and its activities as well as the mineral industry in Nova Scotia.

Table 3. 1989 Public Information Program talks, workshops and field trips.

Date	Location	Audience	Subject
Feb. 24	Prince Arthur Jr. High, Dartmouth	Grade 7	Two talks on rocks and local geology
March 15	Bell Park Academic Centre, Lake Echo	Grades 1 - 6	Five talks on careers in geology
April 17	Bell Park Academic Centre, Lake Echo	Grade 5	Rock and mineral identification and local geology
April 25	Fairview Junior High, Fairview	Junior high level	Careers in geology
May 10, 13	Dartmouth Recreation Dept., Findlay Community Centre	General public	Gold panning course
June 4	Halifax	Community Planning Assoc. of N. S.	Effects of acid rain on building stones
June 7	Port Dufferin	Elderhostels of N. S.	Gold on the eastern shore

June 14	Port Dufferin	Elderhostels	Gold on the eastern shore of N. S.
July 8, 9	Parrsboro	Atlantic Geoscience Society	Geology of the Cobequid Highlands field trip
Aug. 11	Rockhound Roundup, Parrsboro	General public	Field trip about dinosaurs
Aug. 13	Rockhound Roundup, Parrsboro	General public	Boat trip about coastal geology
Aug. 22	Halifax to Parrsboro	Science Teachers	APICS: science teachers field trip
Aug. 24	Atlantic Christian Training Centre, Tatamagouche	Elderhostels of N. S.	Rocks, minerals and land-forms in the Tatamagouche area
Sept. 19, 23	Halifax City Recre-ation Department, Fleming Park	General public	Gold panning course
Sept. 23	Port Dufferin	Elderhostels	Gold on the eastern shore of N. S.
Oct. 27	Halifax	Association of Science Teachers	Economic geology of N. S.; using the new Geological Highway Map

ACADIA UNIVERSITY: DEPARTMENT OF GEOLOGY RESEARCH

J. A. Colwell, Head

INTRODUCTION

Acadia University is located in Wolfville, Nova Scotia, in the eastern Annapolis Valley about 100 km northwest of Halifax. The Geology Department consists of 7 full-time professors, 2 part-time lecturers, and 1 demonstrator. We have 37 undergraduate majors and 9 graduate students.

The Geology Department emphasizes an integrated field and laboratory approach and offers instruction and research training leading to the four year degrees of Bachelor of Science and Bachelor of Science with Honours, and the Master of Science degree. Research funding mainly comes from faculty grants and contracts which are held by most staff. Full-time graduate students also hold fellowships.

Research conducted by the faculty and students is diversified. However, our main thrust is in Nova Scotian geology with various projects involving economic geology, igneous petrology, metamorphic petrology, geochemistry, volcanology, biostratigraphy, paleontology, sedimentology, ichnology, structural geology, regional geology and basin analysis.

RESEARCH PROJECTS IN NOVA SCOTIA

S. M. Barr - continued regional mapping programs On Cape Breton Island. Related petrologic studies emphasize granitoid and volcanic units.

B. W. Cameron - barrier island development; paleontology and stratigraphy of the Scots Bay and Blomidon formations, freshwater and salt marsh peats.

J. A. Colwell - mineral deposits; clay mineralogy, geology of the North Mountain basalt; zeolites.

R. G. Moore - Biostratigraphy of the Windsor Group; geological mapping in the Mosherville, Rawdon and Clarkesville areas.

R. P. Raeside - regional mapping and tectonics of Cape Breton Island; metamorphism of the Meguma Group, southwestern Nova Scotia.

G. R. Stevens - Structural geology, southwestern Nova Scotia; rock fabric; meteor impact.

N. A. Van Wagoner - physical volcanology of the Fourchu Group, Cape Breton Island, in order to determine the paleovolcanic setting of these rocks.

G. M. Yeo - modern estuarine sediments, Cornwallis River; ironstones, Torbrook Formation and Arisaig Group.

M.SC. THESES IN PROGRESS

Sedimentology of the Lower Stellarton units, Pictou County, Nova Scotia (L. Daigle).

Stratigraphy, structure, metamorphism and age of the George River Group, Creignish Hills, Cape Breton Island (J. Campbell).

Basin analysis of the Late Carboniferous upper Cumberland Group - Pictou Group transition of the west-central Cumberland Basin (A. Deal).

M.SC. THESES COMPLETED IN 1989

Petrography, mineral chemistry and geochemistry of dioritic/tonalitic plutons of the southeastern Cape Breton Highlands, Nova Scotia (C. Farrow).

Seismic stratigraphy of part of the upper continental slope off the central Scotian Shelf: Late Mesozoic to Cenozoic sequences (E. Mutunga).

B.SC. THESIS COMPLETED IN 1989

Geology and petrology of the crystalline rocks of the Whycocomagh area, Cape Breton Island, Nova Scotia (A. Armitage).

DALHOUSIE UNIVERSITY: DEPARTMENT OF GEOLOGY FACULTY AND STUDENT RESEARCH IN NOVA SCOTIA

D. B. Clarke, Chairman, and R. A. Jamieson, Graduate Co-ordinator

INTRODUCTION

Dalhousie University in Halifax is well situated and well equipped for research in a range of Earth Science disciplines. The department includes 14 full-time faculty members, 1 instructor, and 6 university technicians, with 16 Ph.D., 13 M.Sc. and 6 B.Sc. honours students (final year) registered in 1989-90.

The department's main strengths are Marine Geology and Appalachian Geology, with many faculty members and their students involved in research on Nova Scotia or its adjacent continental margin. Research is funded largely through the Natural Sciences and Engineering Research Council (NSERC), other government agencies, and contracts; most graduate students hold scholarships or fellowships paid from University and/or research funds.

Research equipment includes a Joel Superprobe (run as a regional facility), conventional and laserprobe $^{40}Ar/^{39}Ar$ dating facilities, a fission track lab (the only university facility of its kind in Canada), X-ray diffraction, atomic absorption and volatile analysis equipment, a high pressure seismic velocity lab, a stable isotope lab, a paleomagnetism lab, and a wide range of geophysical, sedimentological, micropaleontological, computing, petrographic, sample preparation, and photographic equipment. In addition, department members have access to the regional X-ray fluorescence facility at Saint Mary's, and the regional isotope facility (AURIF) now being set up at Memorial University of Newfoundland.

FACULTY RESEARCH (RECENT WORK IN NOVA SCOTIA HIGHLIGHTED)

Ron Boyd - coastal continental shelf sedimentation; sequence stratigraphy (Eastern Shore coastal sedimentation; origin of the Sable Island sand body).

Barrie Clarke - igneous petrology; mineralogy; geochemistry (petrogenesis and geochemistry of peraluminous granites of the Meguma Zone).

Nick Culshaw - structural geology and tectonics; Grenville geology.

Martin Gibling - fluvial sedimentology; coal basins; oil shales (sedimentology and coal deposition in the Sydney Basin).

Jim Hall - crustal drilling; paleomagnetism.

Becky Jamieson - metamorphism and tectonics (regional geology, metamorphism, thermochronometry, and tectonics of the western Cape Breton Highlands).

Franco Medioli - taxonomy of thecamoebans and foraminifera; Pleistocene micropaleontology; biostratigraphy; sea level changes (micropaleontology of Carboniferous and Pleistocene deposits of Nova Scotia and adjacent marine area).

Gunter Muecke - trace element geochemistry; petrology; regional geology and volcanism of the Sverdrup Basin (geochemistry and origin of mineral deposits associated with Meguma Zone granites; structure and metamorphism of the Meguma Zone).

Peter Reynolds - isotope geology, particularly $^{40}Ar/^{39}Ar$ thermochronometry (regional thermochronometry studies in the Meguma Zone, Cape Breton Highlands, Scotian Basin).

Paul Robinson - volcanology; lithological, geochemical, and hydrothermal studies of ocean crust.

Pat Ryall - paleomagnetism; ocean crust drilling (geophysical studies in the Liscomb area).

Paul Schenk - stratigraphy; carbonate petrology; sedimentology and tectonics of the Canadian Appalachians (sedimentology, stratigraphy, and tectonic significance of the Meguma and Windsor Groups).

Dave Scott - micropaleontology; marsh and estuarine foraminfera; Holocene sea level changes; paleo-oceanography (micropaleontology and

Holocene paleo-oceanography of the Scotian Shelf and Bay of Fundy).

Marcos Zentilli - fission track thermochronometry; metallogeny; Appalachian mineral deposits; Andean volcanism and tectonics (mineral deposits of the Meguma Zone; thermal histories of the Carboniferous basins and Scotian Shelf).

ADJUNCT PROFESSORS AND RESEARCH ASSOCIATES

C. Beaumont (Oceanography Department, Dalhousie)
F. Gradstein (Atlantic Geoscience Centre)
M. Salisbury (Atlantic Geoscience Centre)
C. E. Keen (Atlantic Geoscience Centre)
P. R. Hill (Hill Geoscience Research)
L. Jansa (Atlantic Geoscience Centre)
D. J. W. Piper (Atlantic Geoscience Centre)
P. J. Mudie (Atlantic Geoscience Centre)
C. T. Scafer (Atlantic Geoscience Centre)
P. S. Giles (Nova Scotia Department of Mines and Energy)
F. J. Hein
P. Hacquebard

GRADUATE RESEARCH IN NOVA SCOTIA

Completed in 1988:

S. Douma (M.Sc.) The mineralogy, petrology, and geochemistry of the Port Mouton Pluton, Nova Scotia, Canada.

L. Ham (M.Sc.) The mineralogy, petrology, and geochemistry of the Halfway Cove - Queensport Pluton, Nova Scotia, Canada.

S. McLaren (M.Sc.) Quaternary seismic stratigraphy and sedimentation of the Sable Island sand body, Sable Island Bank, outer Scotian Shelf.

G. O'Reilly (M.Sc.) Geology and geochemistry of the Sangster Lake and Larry's River plutons, Guysborough County, Nova Scotia.

L. Richard (M.Sc.) Geochemical discrimination of the peraluminous Devonian-Carboniferous granitoids of Nova Scotia and Morocco.

Completed in 1989:

A. Grist (M.Sc.) Provenance and thermal history of detrital sandstones of the Scotia Basin, offshore Nova Scotia, using the apatite fission track and $^{40}Ar/^{39}Ar$ methods.

In progress, 1989-90:

J. Calder (Ph.D.) Depositional environment and petrography of the Springhill coalfield, northern Nova Scotia.

B. Laidler (M.Sc.) Testate rhizopods from sediments of a marine/freshwater transitional lake, Eastern Shore, Nova Scotia.

T. Martel (Ph.D.) Stratigraphy, sedimentology, and tectonic history of the Horton Bluff Formation.

R. Ryan (Ph.D.) Regional stratigraphy and thermal history of the Cumberland Basin, northern Nova Scotia.

S. Thibaudeau (M.Sc.) Micropaleontology of the Carboniferous Sydney Mines Formation, Cape Breton Island, Nova Scotia.

B.Sc. RESEARCH IN NOVA SCOTIA

Completed in 1988:

M. Brogan - Gravity modelling of the northern boundary of the Liscomb Complex.

R. Kempster - A comparative petrological study of three Nova Scotian intrusions: the Jeddore dyke, the Sober Island dyke, and the Marshdale intrusion.

D. MacDonald - Examination of a zoned pegmatite and host rocks at Port Joli, Nova Scotia.

S. Marsters - A micropaleontological study of cores from the inner Scotian Shelf.

P. Rose - Petrography and geochemistry of anhydrite units from the Canadian Salt Company mine, Pugwash, Cumberland County, Nova Scotia.

T. Soehl - Geological investigation of a mineralized granitic cupola, Kempt Snare Lake, Yarmouth County, Nova Scotia.

Completed in 1989:

J. Jennings - A geophysical study of the Liscomb Satellite Pluton, central Nova Scotia.

K. McKillop - Fission track study of the Jubilee deposit, Cape Breton Island, Nova Scotia.

ST. FRANCIS XAVIER UNIVERSITY: DEPARTMENT OF GEOLOGY

GENERAL

St. Francis Xavier University is located in Antigonish, about 250 km east of Halifax. The geology department consists of 5 staff members, 1 visiting faculty and approximately 30 undergraduate students.

The geology program is designed to provide a strong fundamental background for students who continue to graduate study and at the same time enough practical training to equip those who are immediately employed as professional geologists.

The geology curriculum of the department reflects this aim. Courses such as Mineralogy, Crystallography, Petrology, Stratigraphy and Sedimentation, and Structural Geology are specialized and basic. Applied courses include Ore Deposits, Petroleum Geology, Coal Geology, Geophysics and Geochemistry. The latter provide an opportunity to use and elaborate on the basic principles encountered in earlier geology courses and courses obtained outside this department, especially physics, chemistry and mathematics. There is a seminar course for senior students that is directed to developing the students' capacity to formulate a problem, devise a plan of attack, execute the plan and report the results orally and in written form. Figure 1 illustrates how the various courses are interwoven to form a coherent whole.

LABORATORY STUDIES

The study of rocks in the field is viewed as the most important means of laboratory instruction. To bring together textbook and actual occurrence, certain laboratory periods are devoted to examination in the field. As expected, this is subject to seasonal restrictions.

In a number of branches of earth science, 3-dimensional visualization is extremely important. In Mineralogy, training in 3-dimensional visualization is promoted by the use of crystal models, lattice models and the examination of minerals in their actual crystalline form. In Structural Geology, 3-dimensional training is continued through the use of descriptive geometry and sterographic projection.

Other aspects of laboratory work include the examination of thin sections under the petrographic microscope, analyses of structures on maps and geochemical analyses including work on radiometric dating of rocks.

FIELD CAMP AND SUMMER EMPLOYMENT

At the end of the sophomore year all students are strongly urged to attend the 10 day spring field camp held annually at St. Francis Xavier University. The camp forms the core of the Field Methods course which also involves numerous mapping projects during sophomore, junior and senior years.

In addition, many geology students obtain employment in geological work during the summer. This is regarded as an effective extension of their classroom and laboratory experience.

FACULTY

Here is a brief outline of the geology staff at St. Francis Xavier University:

Alan J. Anderson, Ph.D. (Queens), teaches economic geology, mineralogy and introductory petrology. His research focuses on the techniques and applications of fluid inclusion studies to the understanding of ore deposits.

R. F. Cormier, Ph.D. (M.I.T.), has taught at St. Francis Xavier University for over 30 years. He teaches introductory geology, geochemistry, optical mineralogy, and historical geology. The age determination of rocks, using the ratio of radioactive rubidium to strontium, is his major research activity.

William S. Shaw, Ph.D. (M.I.T.), teaches oil and gas geology, coal geology, and geophysics. He came to St. Francis Xavier University after a long career in oil exploration. Oil, coal, salt and ore deposits are his chief research interests.

J. Brendan Murphy, Ph.D. (McGill), is Chairman of the department and teaches courses concerning

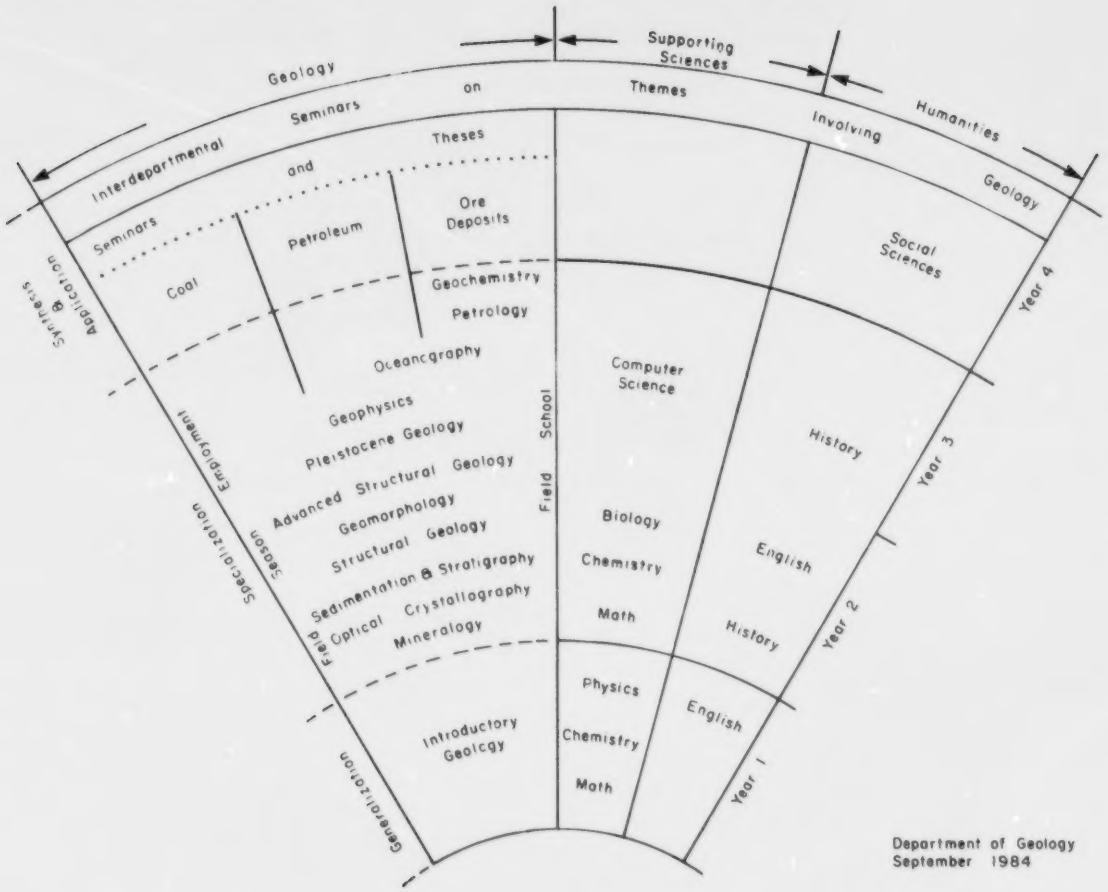

Figure 1. Interrelationship of courses at Saint Francis Xavier University.

the origin of igneous and metamorphic rocks, introductory and regional structural geology, and tectonics. His research interests at present concern the geological evolution of the Antigonish and Cobequid Highland areas and the evaluation of their mineral potential.

Cynthia Murphy, M.Sc. (McGill), teaches stratigraphy and is responsible for computer applications in geology. Her current interest is thegeology of the Gaspé Peninsula in Quebec where she is studying the magmatic history of granitic and volcanic rocks.

Harold Williams, Ph.D. (Toronto), is a visiting James Chair Professor in Geology. His research interests concern the evolution of the Appalachian Orogen.

MINERAL TECHNOLOGY AT THE UNIVERSITY COLLEGE OF CAPE BRETON: A CO-OP EDUCATION PROGRAM

H. R. Oldale

In September 1987, the Mineral Technology program at the University College of Cape Breton (U.C.C.B.) was converted to a 3-year co-operative education format and the first graduates are expected in 1990. The program includes five academic semesters and three four-month job placements (Table 1) leading to a Diploma in Mineral Technology with a co-operative endorsement. The program trains students in geology, mineral exploration, surface and underground mining, mineral processing and analytical chemical methods. Further information is available from the Co-operative Education office (902)539-5300, ext. 129, or the Mineral Department (902)539-5300, ext. 191.

The curriculum objective of the Mineral Technology program since its inception in 1968 has been to provide a strong fundamental background for technical employment in the minerals, exploration, production and processing phases of the minerals industry. Since the first class graduated in 1970, some 133 students have obtained their diplomas and are employed throughout the country in all aspects of the mining and petroleum industries. Many of the earlier graduates now occupy senior technical and management positions.

Initial employment statistics (within three months of graduation) show approximately 20% of the graduates are employed in each of the exploration, mining and mineral processing phases of the mineral resources industry. Analytical laboratory work employs 10%, whereas another 10% are employed in mining-related occupations. Some 15% further their studies and the remaining 5% obtain employment in jobs unrelated to the minerals industry.

Some main features of the curriculum include: (1) a thorough grass roots field exploration project, (2) a complete mine feasibility project, (3) visits to most mining operations throughout the Atlantic Provinces and (4) extensive use of computer applications in all courses.

An industry advisory committee, meeting on an annual or bi-annual basis serves to keep the program current and up-to-date. The committee comprises some 16 senior personnel representing industry, government and educational institutions throughout Nova Scotia and New Brunswick.

FACULTY

F. M. Isenor, Dipl. T., B. Sc., a mining geologist, joined the department in 1981. He is a graduate of the Mineral Technology program and has had seven years industry experience in exploration work and coal mining geology. His teaching responsibilities include geology, surveying and assaying.

C. P. Nicholson, Dipl. T., is a graduate of the Mineral Technology program. He joined the faculty in 1981 after eight years experience in local mining and construction. His teaching duties include laboratory instruction in geology, mining, surveying, computers and exploration, in addition to laboratory maintenance and purchasing responsibilities.

H. R. Oldale, M. Sc., B. Ed., P. Eng., the senior member, joined the Department in December 1967 to set up the program prior to it opening in September 1968. Before 1967 he had spent ten years in geology, mine engineering, development and exploration management. He presently teaches geology and exploration methods.

H. E. Slaunwhite, B. Eng., B. Ed., P. Eng., a mining engineer, has taught in the program since 1969 after working 10 years in mining operations and industrial engineering. He presently teaches mineral processing, mining, computer applications and surveying.

Table 1. Curriculum outline for the Mineralogy Technology program.

SEPT. - DEC.	JAN. - APR.	MAY - AUG.
Year 1		
Academic Term 1	Academic Term 2	Work Term 1
Math I Physics I Communications I Chemistry I Geology I Surveying I	Math II Physics II Communications II Chemistry II Geology II Mining I Computer Programming and Applications	
Year 2		
Academic Term 3	Work Term 2	Academic Term 4
Math III Geology III Mining II Exploration Methods Mineral Process I Drafting I		Math IV Exploration Methods II (field project) Surveying II Assaying I Mineral Process II Drafting II
Year 3		
Work Term 3	Academic Term 5	
	Math V Geology IV Assaying II Mining III Exploration Methods III (mining project)	

APPLIED GEOSCIENCE RESEARCH, NOVA SCOTIA COLLEGE OF GEOGRAPHIC SCIENCES

M. S. Akhavi[1]

INTRODUCTION

Nova Scotia College of Geographic Sciences offers an intensive diploma program in the field of Remote Sensing Technology. Since being founded in 1978, students and faculty have completed over 30 projects in the field of geology and earth sciences with direct cooperation of outside agencies. This effort constitutes about 50% of projects conducted in various disciplines.

RESEARCH FACILITIES

The main research facilities existing at the College include a PCI EASI/PACE microcomputer-based image analyzer, two Aries Dipix digital image processing work stations, and TYDAC SPANS and ESRI ARC/INFO Geographic Information Systems (GIS). Procedures have been established to transfer information between GIS and digital image analysis systems in order to create databases for advanced studies. Also, a variety of micro- and minicomputer environments are employed in the Remote Sensing Program.

TOPICS OF COOPERATIVE STUDIES

A list of geoscience topics previously completed includes: (1) surficial geology investigations and aggregate resource mapping, (2) geological and structural mapping, (3) geocoded database integration utilizing geophysical, geochemical and remotely sensed data for non-renewable resources exploration, (4) mineral exploration and targeting for ore deposits, (5) creation of digital terrain models, (6) geobotanical investigations, (7) rock identification and detection of plutonic phases, (8) engineering terrain mapping, (9) detection of lineaments and (10) delineation of geological hazard zones.

EXAMPLES OF RECENT PUBLICATIONS

The following publications are based on the results of our cooperative project activities:

M. S. Akhavi 1988: Remote Sensing Research over Plutonic Bodies of Nova Scotia; Abstract *in* 1988 Atlantic Geoscience Society Colloquium Program.

M. S. Akhavi 1988: Application of a GIS Analysis System Transfer for Digital Landsat Signature Extraction and Image Classification/Enhancement in Exploration Geology, Progress Summary Report; Energy, Mines and Resources Research Agreements Program, p. 171.

W. P. Jones and M. S. Akhavi 1988: Geological Mapping and Mineral Exploration in Eastern Nova Scotia Utilizing Airborne and Spaceborne Multisensor Data; Geocarto International, v. 3, no. 3, p. 31-36 (in colour).

T. Webster and M. S. Akhavi 1988: Geo-Database Integration in the Antigonish Highlands, Nova Scotia; *in* Nova Scotia Department of Mines and Energy, Report 88-3, pp. 179-180.

S. M. Shupe and M. S. Akhavi 1989: Integration of Remotely Sensed and GIS Data for Mineral Exploration, Halifax Pluton Area, Nova Scotia, Canada; Geocarto International (in press).

S. Gravelle and M. S. Akhavi 1989: Application of GIS and Remote Sensing for Lineament Mapping of Structural Features in the Rouyn-Beauchastel Property, Quebec; Proceedings, IGARSS 89, p. 116-118.

T. Webster and M. S. Akhavi 1988: The Use of Remotely Sensed Data in the Creation of a Geo-Database for Antigonish, Nova Scotia, Utilizing a Micro-Computer Based GIS; Proceedings, IGARSS 89, p. 2034-2036.

S. M. Shupe and M. S. Akhavi 1989: Remote Sensing/GIS Data Integration for Geological Investigation in the South Mountain Batholith near Halifax, Nova Scotia; Proceedings, IGARSS 89, p. 2029-2022.

R. W. Pietsch and M. S. Akhavi 1989: Integration

1 Nova Scotia College of Geographic Sciences, Lawrencetown, Nova Scotia B0S 1M0

of Remote Sensing and GIS for a Hydrogeological Assessment of the Bridgetown, Nova Scotia, area; Proceedings, 7th Thematic Conference on Remote Sensing for Exploration Geology, Calgary, Alberta, Canada, October 2-6, 1989.

INVITATION

The cooperative project program has been highly successful at our College. Students undertake training to conduct projects which are primarily initiated, designed and defined by cooperating sponsors (private, government and(or) academic). Sponsors are expected to supply data for the project, provide technical guidance and offer external review. These projects are of no direct costs to the sponsor; our students benefit from the experience by completing a project using the facilities and instructional support provided by our College.

You are invited to participate in our Cooperative Project Program. Also, please encourage your staff members, colleagues, and other qualified candidates to apply for enrolment in our Remote Sensing Program. This program requires specialized academic training at the post-secondary level. Presently, seven Canadian and three international students are attending our program. Graduates have easily found interesting and viable employment opportunities.

Please direct your inquiries or proposals to:

Dr. M. S. Akhavi
Remote Sensing Program
College of Geographic Sciences
P. O. Box 10, Lawrencetown
Annapolis County, Nova Scotia
B0S 1M0
Telephone - 902-584-2226
FAX - 902-584-7211

GEOLOGY OF THE EASTERN COBEQUID HIGHLANDS: U-PB GEOCHRONOLOGICAL CONSTRAINTS[1]

J. B. Murphy[2], G. Pe-Piper[3], R. D. Nance[4], R. Doig[5] and B. V. Miller[4]

The eastern Cobequid Highlands form part of the northern Appalachian Avalon Terrane (Fig. 1 and Table 1). The highlands are underlain by Precambrian to early Carboniferous rocks (Donohoe and Wallace, 1982, 1985). They are bounded to the south by the E-W to NE-SW Cobequid-Chedabucto fault system, which separates the highlands from the Meguma Terrane. To the north the eastern Cobequid Highlands are unconformably overlain by less deformed middle to late Carboniferous rocks. The Rockland Brook Fault, which parallels the Cobequid Fault, divides the eastern highlands into two fault blocks with contrasting pre-Namurian histories.

Precambrian rocks south of the Rockland Brook Fault (Fig. 1) consist of basement gneiss and amphibolite (Great Village River Gneiss and Mount Thom Complex; Donohoe, 1983) that are structurally overlain by platformal clastic rocks (Gamble Brook Formation) thought to be mid Riphean in age (i.e. ca. 0.8- 1.0 Ga). A ductile shear zone separates the gneiss from the Gamble Brook Formation and obscures the original relationships between these units. Igneous zircons from orthogneiss of the Great Village River Gneiss yield concordant 735 Ma (U-Pb) ages.

The age of the ductile shear zone is given by U-Pb determinations on zircons from syntectonic granite gneiss within the ductile shear zone. These yield ages of 600 Ma. The Gamble Brook Formation is unconformably overlain by interlayered mafic volcanic rocks and thinly laminated turbiditic sedimentary rocks of the Folly River Formation (Murphy et al., 1988). These rocks were intruded by granitic plutons, and appinitic gabbro and diorite (Donohoe and Wallace, 1982). A zircon sample from one of these granite bodies (the Debert River Pluton) yields a 605 Ma age (U-Pb). Hornblende samples from appinite yield a 622 $\pm$ 3 Ma age (Ar-Ar), interpreted as the age of intrusion (Keppie et al., in press).

Three major periods of deformation are considered to be Precambrian (Donohoe, 1983; Cullen, 1984; Nance and Murphy, 1989). The earliest (D1) affects only the gneissic rocks of the Great Village River Gneiss and is associated with development of an amphibolite facies metamorphic fabric. The second period of deformation additionally affects the Gamble Brook Formation as is associated with polyphase ductile shear along the contacts between the gneiss and Gamble Brook Formation platformal sediments. Kinematic studies on this ductile shear zone suggest it was associated with ca. 605 Ma sinistral transtension. This deformation produced a mylonitic fabric and several phases of co-genetic isoclinal folds. Late kinematic, locally sheeted, mafic dykes suggest limited crustal extension and may herald the deposition of the unconformably overlying Folly River Formation. This is supported by the stratigraphy of the Folly River Formation, which is consistent with development of a marine basin, and by the continental tholeiitic, within-plate geochemistry of the mafic volcanic rocks, which indicates that the basin was floored by continental crust (Pe-Piper and Murphy, 1989). Regional considerations suggest that this basin was developed within a volcanic arc and therefore records a volcanic arc rift. A third deformation (D3) pre-dated ca. 600 Ma intrusions, indicating that the Folly River Formation was deposited and deformed between approximately 605 and 600 Ma. The D3 deformation probably resulted in greenschist facies metamorphism, dextral transpression and polyphase NW-directed thrusting in the Folly River Formation. The volcanic arc chemistry of the 622-600 Ma plutons supports the contention that the Folly River Formation was deposited in a volcanic arc rift environment. This third (D3) event is tentatively attributed to closure of a volcanic arc rift (Nance and Murphy, 1989).

North of the Rockland Brook Fault, the late Precambrian Jeffers Group and Warwick Mountain

1 Contribution to the Canada - Nova Scotia Mineral Development Agreement, 1984-89
2 Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia B2G 1C0
3 Department of Geology, St. Mary's University, Halifax, Nova Scotia B3H 3C3
4 Department of Geology, Ohio University, Athens, Ohio OH 45701
5 Department of Geological Sciences, McGill University, Montreal, Quebec H3A 2A7

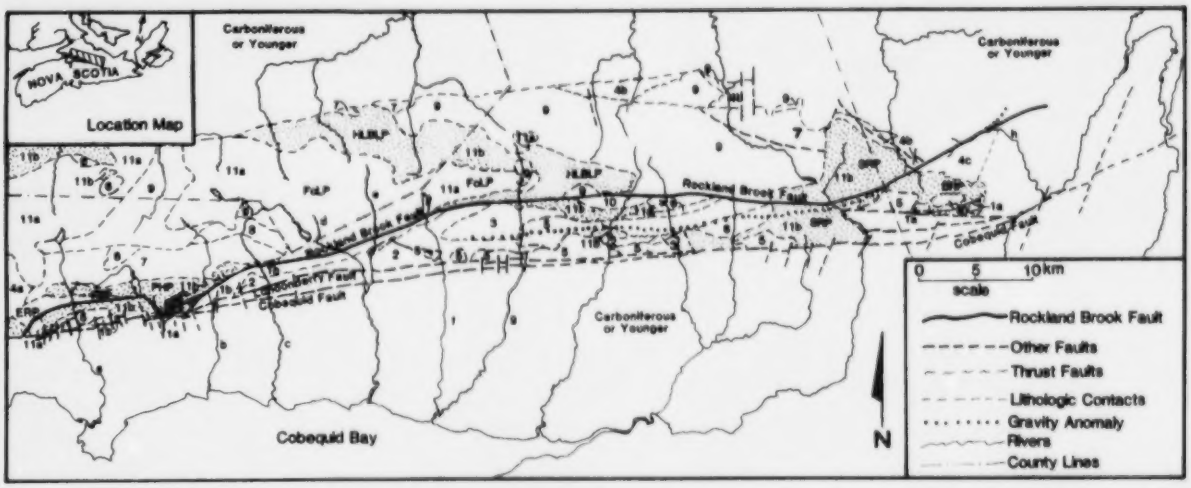

Figure 1. Geological map of the eastern Cobequid Highlands, Nova Scotia, adjacent to the Rockland Brook Fault (RBF) (modified after Donohoe and Wallace, 1982, and Murphy et al., 1988). See Table 1 for legend. Identified Devono-Carboniferous plutons include the Hart Lake-Byers Lake (HLBLP), Pleasant Hills (PHP) and Salmon River (SRP) granites, and the Folly Lake (FoLP) and Economy River (ERP) diorites. Identified locations are as follows: (a) Economy River; (b) Bass River; (c) Portapique River; (d) Great Village River; (e) Rockland Brook; (f) Folly River; (g) Debert River; and (h) Six Mile Brook.

Table 1. Legend to Figure 1 (stratigraphy modified after Donohoe and Wallace, 1982, and Murphy et al., 1988).

11	Devono-Carboniferous plutons (a) gabbro/diorite (b) granite
10	Nuttby Formation
9	Fountain Lake Group
8	Portapique River and Murphy Brook formations
7	Wilson Brook Formation
6	Silurian volcanics and other undivided Silurian rocks
5	Late Precambrian-Cambrian plutons
4	(a) Jeffers Group (b) Warwick Mountain Formation (c) Dalhousie Mountain volcanics
3	Folly River Formation
2	Gamble Brook Formation
1	(a) Mount Thom Complex (b) Great Village River Gneiss

Formation consist of arc-related mafic to felsic volcanic rocks overlain by a thick sequence of turbidites (Pe-Piper and Piper, 1989). Detailed correlations between late Precambrian volcano-sedimentary rocks in the Cobequid and Antigonish Highlands are proposed. These correlations indicate that the stratigraphy in these areas may be related to development of the same volcanic arc rift and provide constraints on palinspastic reconstructions.

Cambrian to mid-Ordovician rocks are not exposed in this area. Late Ordovician to Early Devonian rocks consist of fossiliferous, unmetamorphosed, siliciclastic sedimentary rocks in part named the Earltown Formation by Donohoe and Wallace (1982). North of the Rockland Brook Fault, they strongly resemble the Arisaig Group of the northern Antigonish Highlands. They contain Rhenish-Bohemian faunal assemblages that are diagnostic of the Avalon Terrane. South of the Rockland Brook Fault rocks of a similar age are nonfossilferous and poorly exposed. Their relationship to other sequences of the same age north of the Rockland Brook Fault is not understood.

Devono-Carboniferous rocks consist of siliceous continental sedimentary rocks to the south and ca. 340 Ma bimodal volcanic rocks (Rb-Sr whole rock, R. F. Cormier, personal communication, 1986) to the north of the Rockland Brook Fault. The relationship between these two sequences is unknown. Geochemical studies (Dostal et al., 1983) indicate that the volcanic rocks were emplaced into an intra-continental, rift-related environment.

Voluminous Devono-Carboniferous plutonic rocks are the oldest lithology to occur on both sides of the Rockland Brook Fault in the eastern Cobequid Highlands. The plutonism is bimodal, within-plate, continental and rift-related and in part may be related to the volcanism described earlier (Pe-Piper et al., 1989). Zircon samples from granitic rocks of the Pleasant Hills Pluton

yield U-Pb ages of 360 Ma. The Hart Lake-Byers Lake granite has yielded a Rb-Sr whole rock age of 348 ± 3 Ma (Donohoe et al., 1986). This igneous activity is related to local extension along the Cobequid Fault and other major strike-slip faults.

The highlands were heterogeneously deformed by E-W to NE-SW faults that broadly parallel the Cobequid Fault. The time of this deformation is bracketed between Tournaisian and Westphalian (Donohoe and Wallace, 1985). The resultant deformation re-activated and re-oriented Precambrian faults and locally produced an intense mylonitic fabric, positive flower structures, en echelon isoclinal folds and genetically-related thrusts associated with a dextral, locally transpressive strike-slip regime (Miller et al., 1989). This interpretation is consistent with regional studies that suggest the Avalon Terrane underwent regional dextral shear at this time.

ACKNOWLEDGMENTS

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SUMMARY REPORT OF SECONDARY SULPHATE MINERALS, SYDNEY COALFIELD, NOVA SCOTIA, CANADA[1]

E. L. Zodrow[2]

INTRODUCTION

Blooms of secondary sulphate minerals (hydrated, anhydrous; acid, normal, hydroxyl or halogen containing) occur as a result of oxidation of sulphurous coal and certain associated rocks both in underground coal mines and on the surface in the Sydney Coalfield. The sulphates are very interesting because of their biochemical origin, as concluded from the sulphur-isotopic composition (Zodrow, in press).

Based on field and underground observations over the past 13 years, and on studying over 400 powder samples by X-ray diffraction methods, 20 X-ray films, and chemical compositions of over 40 samples, the presence of 36 sulphate minerals has been documented. General mineralogy has been summarized, which is not readily available in the literature (Casagrande, 1987; Bouska, 1981; Palache et al., 1957).

REPOSITORY

Samples of the studied sulphate minerals (Table 1), as well as extensive collections yet to be studied from the Sydney Coalfield, have been curated by the author and stored at the University College of Cape Breton, Sydney, Nova Scotia. I have also donated suites of secondary sulphates from Sydney to the Smithsonian Institution, Washington, D. C.; Museum of Mineralogy, Paris, National Museum of Canada, Ottawa, and Michigan State University, Ann Arbour (Zodrow, 1980).

ANALYTICAL METHODS

The chemical analysis of sulphates was done by wet chemistry atomic absorption, and flame photometry (Zodrow et al., 1979). For X-ray diffraction (XRD) and for crystallochemistry Fe/Mn, Fe/Co, Ni/Cu, or Fe/Cu radiators were used with minimum exposure time of four hours. Debey-Scherrer cameras with either 114.6 or 57.3 mm diameters were used for film preparations. Differential thermogravimetric analysis (DTG) helped establish co-ordinated water content in the unit cell of some sulphate samples. Scanning electron microscopy (SEM) was used as an additional tool to help identify the minerals.

GENERAL MINERALOGY

The studied minerals are listed in Table 1. They are soft (H = 1-2), not too dense (D = <2-<3), and pulverulent, preventing study of single crystals to confirm symmetry. Most of the minerals are water soluble. Orthorhombic fibroferrite is one exception and reacts with water (hydrolysis) to form an acid solution (pH approximately 2.6) and a pure white precipitate. It consists of crystals which show acicular habit and parallel optical extinction, indicating the orthorhombic crystal system. No positive mineral match was possible, but the structure of the precipitate is close to fibroferrite (12).

The secondary sulphates vary in colour from white, light green (ferrous tamarugite: 33), and green (melanterite: 21), to shades of yellow and pink, red (amarantite: 3), and a dark olive green-grey (fibroferrite: 12). The copiapites are yellow and commonly referred to as 'sulphur blooms'. Aluminocopiapite (1) is deep yellow making it easy to recognize. Generally, ferrous iron-containing phases show green colour.

Some sulphates may be used as an index of an acid environment because they form only at lower pH values (Table 1; thenardite: 34) and rhomboclase: 27) (Zodrow et al., 1979).

Following the classification of Palache et al. (1957), the majority (36%) of sulphates studied crystallize in the monoclinic unit cell, followed by 21% in each of the triclinic and hexagonal cells, 18% in the orthogonal, and 3% (voltaite: 36) in the isometric cell.

XRD studies indicate that not all sulphate samples were sufficiently crystallized for diagnostic identification when sampled. Storage in

1 Funded by the Natural Sciences and Engineering Research Council of Canada
2 Department of Geology, University College of Cape Breton, Sydney, Nova Scotia, Canada B1P 6L2

Table 1. Secondary sulphate minerals in Sydney Coalfield, Nova Scotia, Canada.

Name	Formula	Investigated using
(1) Aluminocopiapite*	$(Al,Mg)\ Fe^{+3}_4(SO_4)_6(OH)_2 \cdot 20H_2O$	XRD[1], CHEMISTRY, SEM[2]
(2) Alunite	$KAl_3(SO_4)_2 \cdot (OH)_6$	XRD
(3) Amarantite	$Fe(SO_4)\ (OH) \cdot 3H_2O$	XRD
(4) Amarillite	$NaFe(SO_4)_2 \cdot 6H_2O$	XRD, CHEMISTRY
(5) Bieberite(?)	$Co(SO_4) \cdot 7H_2O$	XRD
(6) Bloedite	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	XRD
(7) Coquimbite	$Fe_2(SO_4)_3 \cdot 9H_2O$	XRD
(8) Dietrichite	$ZnAl_2(SO_4)_4 \cdot 22H_2O$	XRD
(9) Epsomite and	$Mg(SO_4) \cdot 7H_2O$	XRD
(10) Mn-rich epsomite	not reported in literature	XRD, CHEMISTRY
(11) Ferroan copiapite*	$Fe^{+2}Fe^{+3}_4(SO_4)_6(OH)_2 \cdot 20H_2O$	XRD, CHEMISTRY, DTG[3]
(12) Fibroferrite	$Fe(SO_4)\ (OH) \cdot 5H_2O$	XRD, CHEMISTRY, DTG
(13) Gypsum	$CaSO_4 \cdot 2H_2O$	XRD
(14) Halotrichite	$Fe^{+2}Al_2(SO_4)_4 \cdot 22H_2O$	XRD, CHEMISTRY
(15) Hexahydrite	$Mg(SO_4) \cdot 6H_2O$	XRD
(16) Hohmannite	$Fe_2(SO_4)_2(OH)_2 \cdot 7H_2O$	XRD
(17) Jarosite	$KFe_3(SO_4)_2(OH)_6$	XRD
(18) Kirovite	$(Fe,Mg)\ SO_4) \cdot 7H_2O$	XRD
(19) Mg copiapite*	$(Mg)Fe^{+3}_4(SO_4)_6(OH)_2 \cdot 20H_2O$	XRD, CHEMISTRY, DTG
(20) Mg-ferroan* copiapite	$(Mg,Fe)Fe^{+3}_4(SO_4)_6(OH)_2 \cdot 20H_2O$	XRD, CHEMISTRY, DTG, SEM
(21) Melanterite	$Fe(SO_4) \cdot 7H_2O$	XRD, CHEMISTRY
(22) Metasideronatrite#	$Na_4Fe_2(SO_4)_4(OH)_2 \cdot 3H_2O$	DTG
(23) Metavoltine	$(K,Na\ Fe)_5Fe^{+3}_3(SO_4)_6(OH)_2 \cdot 9H_2O$	XRD, SEM
(24) Natrojarosite	$NaFe_3(SO_4)_2 \cdot (OH)_6$	XRD, CHEMISTRY
(25) Paracoquimbite	$Fe_2(SO_4)_3 \cdot 9H_2O$	XRD
(26) Pickeringite	$MgAl_2(SO_4)_4 \cdot 22H_2O$	XRD, CHEMISTRY
(27) Rhomboclase	$FeH(SO_4)_2 \cdot 4H_2O$	XRD
(28) Roemerite	$Fe^{+2}Fe^{+3}_2(SO_4)_4 \cdot 14H_2O$	XRD
(29) Rozenite	$Fe(SO_4) \cdot 4H_4O$	XRD, CHEMISTRY
(30) Sideronatrite	$Na_2Fe(SO_4)_2(OH) \cdot 3H_2O$	XRD, CHEMISTRY, DTG
(31) Siderotil(?)	$Fe(SO_4) \cdot 5H_2O$	XRD
(32) Tamarugite	$NaAl(SO_4)_2 \cdot 6H_2O$	XRD, CHEMISTRY
(33) Ferrous tamarugite	not reported in literature	XRD, CHEMISTRY
(34) Thenardite	Na_2SO_4	XRD
(35) Ungemachite(?)	$Na_9K_3Fe(SO_4)_6(OH)_3 \cdot 9H_2O$	XRD
(36) Voltaite	$(KFe^{+2})_3Fe^{+3}(SO_4)_3 \cdot 4H_2O$	XRD

* for chrystallochemistry see Zodrow (1989).
\# not found in nature, obtained from sideronatrite by DTG.
[1] XRD X-ray diffraction
[2] SEM Scanning electron microscope
[3] DTG Differential thermogravimetric analysis

a dry, cool place for a few weeks usually improves the degree of crystallization, resulting in more intense XRD lines. Minor amounts of unidentified phases are present in almost every sample, but the X-ray lines may be of low intensity and cannot readily be matched with those of known sulphate minerals. In an extreme case, a seemingly homogeneous halotrichite (14) sample showed that it was approximately 55% pure; of the remainder, 35% was melanterite (21) and 10% could not be matched with known powder files.

Sulphate mineral associations are important because they illustrate some basic mineralogical principles (Zodrow, 1989):

(a) diadochic series (isomorphic series),
(b) dehydration sequence,
(c) paragenesis, and
(d) a probable combination of (a) and (b).

SUMMARY

Coal outcrops and underground coal mines in the Sydney Coalfield furnish laboratories with *in situ* studies of secondary sulphate minerals, their generation and alteration. The mineralogy is complicated and for many samples in the collections cell parameters remain to be worked out, as well as isotypic and isomorphic relationships, and sulphur-isotopic compositions. Crystallochemical parameters obtained for some secondary sulphate mineral samples from Sydney compare with those of the copiapite group (Berry, 1947). Among them are alumino- and magnesiocopiapites. The minerals form as a result of pyritic oxidation in coal without intermediate compound formation, precipitation from acid-mine flow, or paragenesis starting with pyrite (Zodrow et al., 1979; Zodrow, in press). The role of pyrite as sole donor of sulphur for the formation of secondary sulphates is currently under investigation. Potential sulphur donors include organic and possibly elemental sulphur. As part of the current investigation, the role of *Thiobacillus* bacteria in the formation of SO_4^{-2} for biochemical sulphate mineralization is being probed. A large degree of sulphur fractionation (Zodrow, 1989) supports a bacterial role and has prompted further study.

It is interesting to note that generally the Fe, Al and Mg chemistry of the copiapites reflects the bulk composition of the coal with respect to these elements (Zodrow, in press). It can be documented for the Sydney Coalfield that coal pillars and walls left standing as roof supports in the old underground workings progressively disintegrate as a result of the combined processes of sulphate-crystallization pressure and attendant dehydration of the coals.

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GEOLOGY OF THE METAMORPHIC ROCKS OF THE BOISDALE HILLS, CAPE BRETON ISLAND[1]

R. P. Raeside[2]

INTRODUCTION

The Bras d'Or Terrane (Barr and Raeside, 1989) includes several blocks of basement rocks that outcrop across central Cape Breton Island and in the southeastern Cape Breton Highlands (Fig. 1). The terrane is distinguished by the occurrence of a suite of low pressure gneisses and by rocks of the George River Group (Barr and Raeside, 1986, 1989). Intruded into the Bras d'Or Terrane are large plutons of late Precambrian to early Cambrian age (Barr and Setter, 1986; Barr et al., 1982; Raeside and Barr, in press) that appear to have been generated in an island arc setting (Farrow and Barr, 1989).

The diagnostic unit of the Bras d'Or Terrane was considered by Barr and Raeside (1986, 1989) to be the George River Group. Preliminary investigations indicate that this unit is restricted to the Bras d'Or Terrane, where it is typically at low metamorphic grade, except where it has been intruded by post-metamorphic plutons. Outcrops of low pressure gneiss and schist of higher metamorphic grade have been reported in several parts of the Bras d'Or Terrane and appear to constitute a second diagnostic unit (Barr and Raeside, 1989).

GEOLOGY OF THE BOISDALE HILLS

The Boisdale Hills are located on the eastern margin of the Bras d'Or Terrane (Fig. 1). They were included in regional mapping by Bell and Goranson (1938), Weeks (1954) and Kelley (1967). The pre-Carboniferous rocks of the Boisdale Hills were mapped by and Barr and Setter (1986) who were concerned primarily with the igneous rocks of the area. Two pre-Carboniferous stratified units were recognized: the Precambrian George River Group, and undifferentiated Cambrian(?) rocks of the Bourinot Group, and the MacMullin, MacNeil and McLeod Brook formations. The purpose of this study is to investigate the geology of the George River Group, as shown by Barr and Setter (1986), in view of the recent re-allocation of rocks assigned to the George River Group to other units, particularly the Bras d'Or gneiss (Barr and Raeside, 1989).

George River Group

Although no type section has been formally defined for the George River Group, the term has been variably applied to many of the low grade stratified units of Cape Breton Island. Milligan (1970) described outcrops of the "George River Series" in central Cape Breton Island, some of which have since been assigned to the McMillan Flowage Formation (Raeside and Barr, 1986, in press) or have been distinguished as higher grade gneissic units (Armitage, 1989; Raeside, 1987; Raeside et al., unpublished data). In the Boisdale Hills (Fig. 1), all outcrops west of, or incorporated in, the Shunacadie Pluton and outcrops in the Ironville and Long Island areas (Barr and Setter, 1986) appear to be part of the George River Group (*sensu stricto*). Throughout these areas, the metamorphic grade is uniformly low and the sedimentary or volcanic protolith can be readily identified. The dominant rock type is impure quartzite, containing small amounts of mica and feldspar. With increasing amounts of mica this grades into a metagreywacke and, in the most micaceous rocks, slate or phyllite depending on the local metamorphic grade. Mafic rocks are rare; they are actinolite-epidote-albite rocks and may or may not display a pronounced foliation. Prehnite-bearing greenstones, with recognizable relict porphyritic and vesicular textures, occur in the southwestern part of the area. No calcareous rocks were found in the George River Group (*sensu stricto*) of the Boisdale Hills.

Metamorphic grade in pelites is generally in the chlorite zone; biotite is present in less than half the thin sections observed, and is abundant only within 500 m of contact with the Shunacadie Pluton. Immediately adjacent to the pluton in Hare Brook and in the Shunacadie area, spotted cordierite slate,

1 Funded by the Natural Sciences and Engineering Research Council of Canada, operating grant to R. Raeside
2 Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0

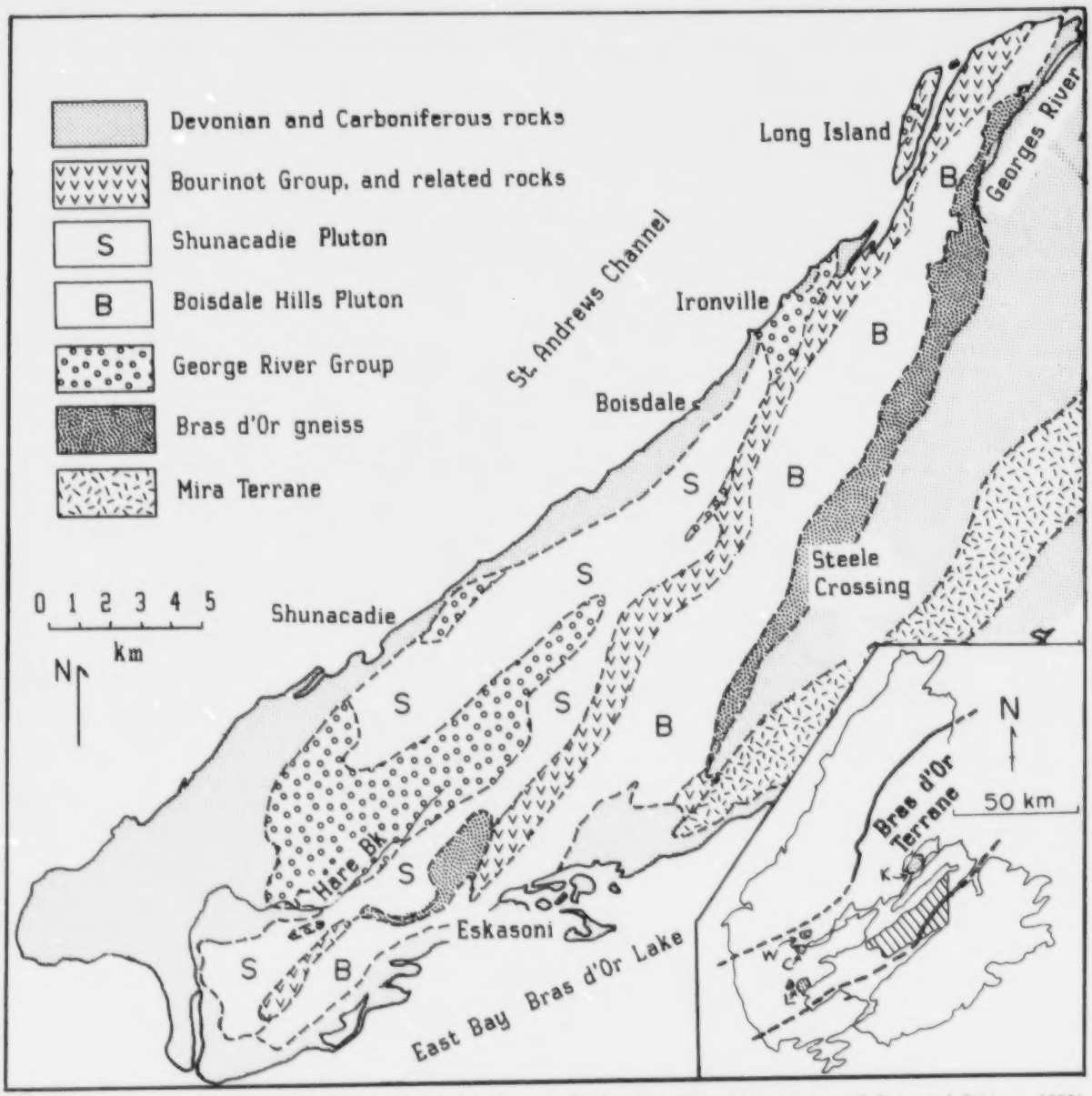

Figure 1. Location of the stratified units in the Boisdale Hills area (based on mapping of Barr and Setter, 1986). Inset: location of the Boisdale Hills in the Bras d'Or Terrane, Cape Breton Island. Shaded area = Boisdale Hills, C = Creignish Hills gneiss, K = Kellys Mountain Gneiss, L = Lime Hill gneiss, W = Whycocomagh Mountain gneiss.

phyllite and hornfels occur. In metabasites, the occurrence of actinolite, epidote, chlorite and albite is typical of the lower greenschist facies, and the perseverance of prehnite in some areas suggests metamorphic conditions on the edge of the prehnite-pumpellyite facies.

Bras d'Or gneiss

Rocks that were assigned to the George River Group by Barr and Setter (1986) and that outcrop east of the Boisdale Hills Pluton and in the Eskasoni area are distinct from the George River Group (*sensu stricto*) described above. These rocks include outcrops in the Georges River area and in the area of Steele Crossing and to the northeast, which have been described by Milligan (1970) and reported as contact metamorphic by Chatterjee (1977). They are informally termed the Bras d'Or gneiss here. The dominant rock types in this area are marble, impure marble and calc-silicate rocks. Pelitic, semipelitic and psammitic rocks do occur,

but make up less than 20% of the unit, in contrast to the George River Group (*sensu stricto*). Detailed descriptions of the composition of components of the Bras d'Or gneiss are given by Armitage (1989), Jamieson (1984) and Justino and Sangster (1987).

The contrast between the George River Group (*sensu stricto*) and the Bras d'Or gneiss is further emphasized by the difference in metamorphic grade. The gneissic rocks show uniformly high metamorphic grade and pelitic rock types are biotite gneiss, some of which contain cordierite, andalusite or sillimanite. Sillimanite-biotite gneiss is the most abundant pelitic rock type and is typically composed of quartz, biotite, muscovite, sillimanite (both coarse grained and fibrolitic varieties) and plagioclase. Cordierite or garnet may be present and Fe-Ti oxides are ubiquitous. Cordierite and garnet appear to be mutually exclusive: samples that contain both minerals display garnet-breakdown textures. Coarse grained andalusite is associated with cordierite and sillimanite.

The more abundant calcareous rocks of the Bras d'Or gneiss in the Boisdale Hills are less useful in distinguishing the affinity of the unit. Pure marble is common and is typically a coarse grained white rock. Impure marbles typically contain some combination of diopside, forsterite or tremolite, with the forsterite commonly retrograded to serpentine. These assemblages are compatible with the low pressure, upper amphibolite facies assemblages observed in pelitic rocks.

The maximum prograde metamorphic assemblage in pelitic rocks of the Bras d'Or gneiss in the Boisdale Hills is biotite, cordierite, sillimanite, plagioclase, orthoclase, quartz, ilmenite, magnetite and melt (migmatites). This assemblage limits peak metamorphism, based on aluminosilicate stability and on various melt-producing reactions, to the range 300 to 450 MPa and over 600° C (Fig. 2). Retrograde metamorphism has been prevalent in much of the gneiss, resulting in development of secondary muscovite, sericite, pinite and chlorite.

CORRELATION OF THE METAMORPHIC ROCKS OF THE BOISDALE HILLS

The pronounced contrasts in rock type and metamorphic grade indicate that two Precambrian stratigraphic units exist in the Boisdale Hills. Both were intruded by the 564 +3/-2 Ma (G. R. Dunning, personal communication, 1989) Shunacadie Pluton but contact effects are only

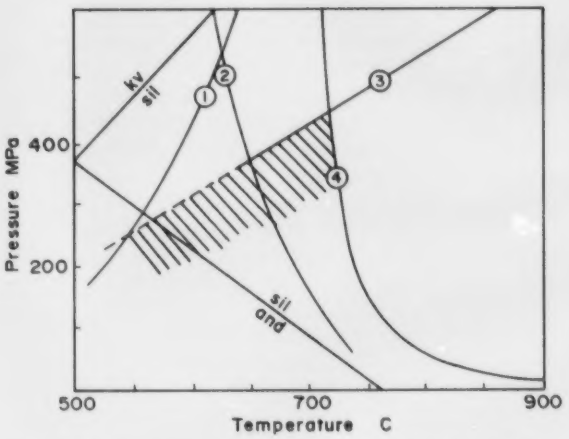

Figure 2. Pressure-temperature conditions for the Bras d'Or gneiss of the Boisdale Hills. Numbered reactions are 1, muscovite + albite + quartz = K-feldspar + Al_2SiO_5 + H_2O (Thompson and Tracy, 1979); 2, Al_2SiO_5 + albite + quartz + K-feldspar + H_2O = melt (Thompson and Tracy, 1979); 3, biotite + Al_2SiO_5 + quartz = cordierite + K-feldspar + H_2O; 4, biotite + K-feldspar + sillimanite + quartz + H_2O = melt (Seifert, 1976).

obvious in the low grade rocks of the George River Group (*sensu stricto*).

The higher grade, dominantly calcareous rocks of the eastern Boisdale Hills display similar characteristics to other outcrop areas of the Bras d'Or gneiss including the Kellys Mountain Gneiss (Jamieson, 1984), the Lime Hill gneiss (Raeside, 1987, in press), the Whycocomagh Mountain gneiss (Armitage, 1989) and the gneiss in the eastern Creignish Hills (Armitage, 1989; Campbell, personal communication). Typical is the occurrence of low pressure, upper amphibolite facies assemblages and the scarcity of garnet-bearing rock types. Many of the pelitic rocks appear to be Mg-rich and have developed cordierite-biotite assemblages. It is proposed that all these gneissic units are correlative (Barr and Raeside, 1989) and are here referred to collectively as the Bras d'Or gneiss. Calcareous rock types are relatively abundant in the Bras d'Or gneiss of the eastern Boisdale Hills, although they are also present in lesser amounts in most of the other outcrop areas. Typically they are diopside- or forsterite-bearing rocks, indicative of amphibolite facies metamorphism.

The recognition of several outcrop areas of high grade, low pressure gneiss in the Bras d'Or Terrane indicates that a regional high heat flow event was responsible for the metamorphism, as suggested by Armitage (1989) who concluded that the Bras d'Or gneiss formed within a geothermal gradient of 70° to 100°C/km in a continental rifting (possibly back-arc spreading) environment.

The George River Group (*sensu stricto*) in the western Boisdale Hills is similar in rock type and grade to other outcrops previously assigned to the George River Group in the Creignish Hills (Milligan, 1970; Campbell, personal communication), Whycocomagh Mountain and the Aberdeen Ridge (Armitage, 1989). Outcrops in North Mountain (Marble Mountain area) contain calcareous rocks and appreciably larger amounts of mafic rocks, but are probably correlative, based on the abundance of impure quartzite, metagreywacke and slate, their apparent Precambrian age, and their relatively low metamorphic grade.

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THE MAIN-A-DIEU SEQUENCE: AN EXTENSIVE LATE PRECAMBRIAN VOLCANIC-SEDIMENTARY PACKAGE IN SOUTHEASTERN CAPE BRETON ISLAND[1]

S. M. Barr[2] and C. E. White[2]

INTRODUCTION

As a result of systematic re-mapping of pre-Carboniferous volcanic, sedimentary, and plutonic rocks in southeastern Cape Breton Island (Barr et al., 1987, 1888a, 1988b; 1989a, 1989b, in press), rocks to the northeast of Louisbourg Harbour that were previously included in the Fourchu Group (Weeks, 1954; Murphy, 1977; Keppie, 1979) have been re-assigned to a separate unit named the Main-a-Dieu sequence (Fig. 1 and Table 1). Excellent exposures of typical rocks of the sequence occur in the area of Main-a-Dieu Bay. Rocks of the Main-a-Dieu sequence also occur locally along the northwestern margin of the Coastal belt of the Fourchu Group (Fig. 1). The Main-a-Dieu sequence is inferred to be younger than and to unconformably overlie the Fourchu Group.

The purpose of this report is to focus attention on the Main-a-Dieu sequence and to briefly describe its characteristics. Field data, detailed descriptions of rock units, and geochemical data from volcanic units and associated intrusions are presented by Barr et al. (in press).

FIELD RELATIONS

Contacts between the Main-a-Dieu sequence and the Fourchu Group are not exposed, but in the area around Louisbourg Harbour and to the north, the change from Fourchu to Main-a-Dieu lithologies occurs over distances of only a few tens of metres. To the west of the Coastal belt, a major fault, here named the L'Archeveque - Mira Bay fault, separates the Main-a-Dieu sequence from the Fourchu Group (Fig. 1).

The Main-a-Dieu sequence unconformably underlies a distinctive red siltstone, sandstone, and conglomerate unit, part of the Late Precambrian - Early Cambrian Morrison River Formation of Hutchinson (1952) and Weeks (1954). This redbed unit is overlain unconformably(?) by grey quartzite and quartzitic conglomerate and grey to black slate, siltstone and wacke (Fig. 1). The latter unit is part of the widespread upper Lower Cambrian and younger sedimentary succession of southeastern Cape Breton Island as defined by Hutchinson (1952).

From these field relations the Main-a-Dieu sequence is inferred to be Late Precambrian to Early Cambrian in age. This is further supported by lithological similarity of the Main-a-Dieu rocks to units in the Caledonia Highlands of southern New Brunswick (Barr and White, 1988) which have yielded U-Pb (zircon) ages of about 550 Ma (Bevier and Barr, in press).

CHARACTERISTICS OF THE MAIN-A-DIEU SEQUENCE

The Main-a-Dieu sequence is divided into thirteen lithological units (Fig. 1 and Table 1). The most distinctive lithologies are laminated siltstones (or possibly ash-tuffs) of unit 1, amygdaloidal basalt flows of units 2, 5 and 7, maroon to green conglomerates or lapilli tuffs (which may be lahars) of units 5, 6, 7 and 13, massive dark-coloured crystal-lithic tuffs of unit 11, and red and green heterolithic lapilli tuffs of unit 12.

The rocks of the Main-a-Dieu sequence are typically less cleaved and contain much better preserved primary depositional textures and structures than rocks of the Coastal belt to the southwest of Louisbourg Harbour. Volcaniclastic sedimentary rocks are dominant, together with basaltic and rhyolitic flows and autobreccias. Crystal and lithic-crystal tuffs of intermediate composition, which dominate in the Coastal belt, are essentially absent.

Layering (but not foliation) in the Main-a-Dieu sequence forms an arcuate pattern through Cape Breton and Scaterie Island (Fig. 1). Aeromagnetic maps of the area show a corresponding arcuate pattern of magnetic

1 Funded by Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement

2 Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0

Table 1. Legend for geological map of the Main-a-Dieu sequence and overlying rocks.

CARBONIFEROUS	
C	Undivided basal breccia, sandstone, limestone, conglomerate
EARLY TO MIDDLE CAMBRIAN	
Csl	Grey to black slate, slaty siltstone, wacke
Cqz	Grey quartzite, quartzitic conglomerate
LATE HADRYNIAN - EARLY CAMBRIAN(?)	
HCrb	Red siltstone, sandstone, conglomeratic wacke, conglomerate
gb	Gabbro (gbB = Baleine gabbro)
	MAIN-A-DIEU SEQUENCE
13	Maroon lapilli tuff/conglomerate
12	Varied heterolithic lapilli tuff (commonly maroon to red and green), basalt and basaltic lapilli tuff
11	Black to dark grey, siliceous crystal-lithic tuff (magnetite-rich)
10	Fine grained dacitic to rhyolitic tuff, dacitic lapilli tuff/conglomerate, minor fine grained laminated siltstone
9	Grey-green laminated siltstone; minor wacke and basalt
8	Varied maroon to buff-coloured rhyolitic lithic tuff
7	Volcanogenic conglomerate; buff to green and maroon laminated siltstone; basalt (7B = mappable basaltic flows)
6	Maroon to green conglomerate and siltstone; lapilli tuff/conglomerate
5	Mafic to intermediate lapilli tuff/conglomerate; thin amygdaloidal basalt flows; maroon siltstone
4	Varied rhyolitic tuffs and flows(?); minor maroon siltstone
3	Intermediate to felsic lapilli tuff/conglomerate
2	Amygdaloidal basalt; basaltic lapilli tuff; maroon siltstone
1	Grey-green siliceous laminated siltstone/ash tuff (commonly displaying evidence of slumping); lapilli tuff conglomerate; abundant dacitic porphyry sills

anomalies (D. B. Loncarevic, personal communication, 1988). Foliation is typically weakly developed but, where present, trends northeasterly.

Younging directions in the Main-a-Dieu sequence are to the southeast in unit 1 northeast of Louisbourg Harbour, to the northeast on the shore of Main-a-Dieu Bay and on Scatarie Island, to the north on the south shore of Mira Bay, and to the northwest in the part of the sequence along the western side of the Coastal belt. Hence the Main-a-Dieu sequence appears to form a broad anticlinal structure around the northeastern end of the Coastal belt.

With the exception of subvolcanic porphyries and sheets probably comagmatic with the host volcanic units, plutonic rocks in the Main-a-Dieu sequence are gabbroic in composition. The largest is the Baleine gabbro (Fig. 1).

Geochemical data from basaltic layers (mainly unit 7) in the Main-a-Dieu sequence range in SiO_2 content from about 45 - 55% (basalt to basaltic andesite) and indicate tholeiitic character (Barr et al., in press). They appear to have formed in an extensional setting within a volcanic arc.

IMPLICATIONS

Our preliminary interpretation is that the Main-a-Dieu sequence is younger than the Fourchu Group, although it could also be a lateral facies equivalent. Some map units within the Stirling belt and East Bay Hills are lithologically similar to some Main-a-Dieu units, and the sequence may be more extensive in southeastern Cape Breton Island than shown on Figure 1. U-Pb dating of felsic volcanic units is in progress to attempt to clarify the age relationships and stratigraphy.

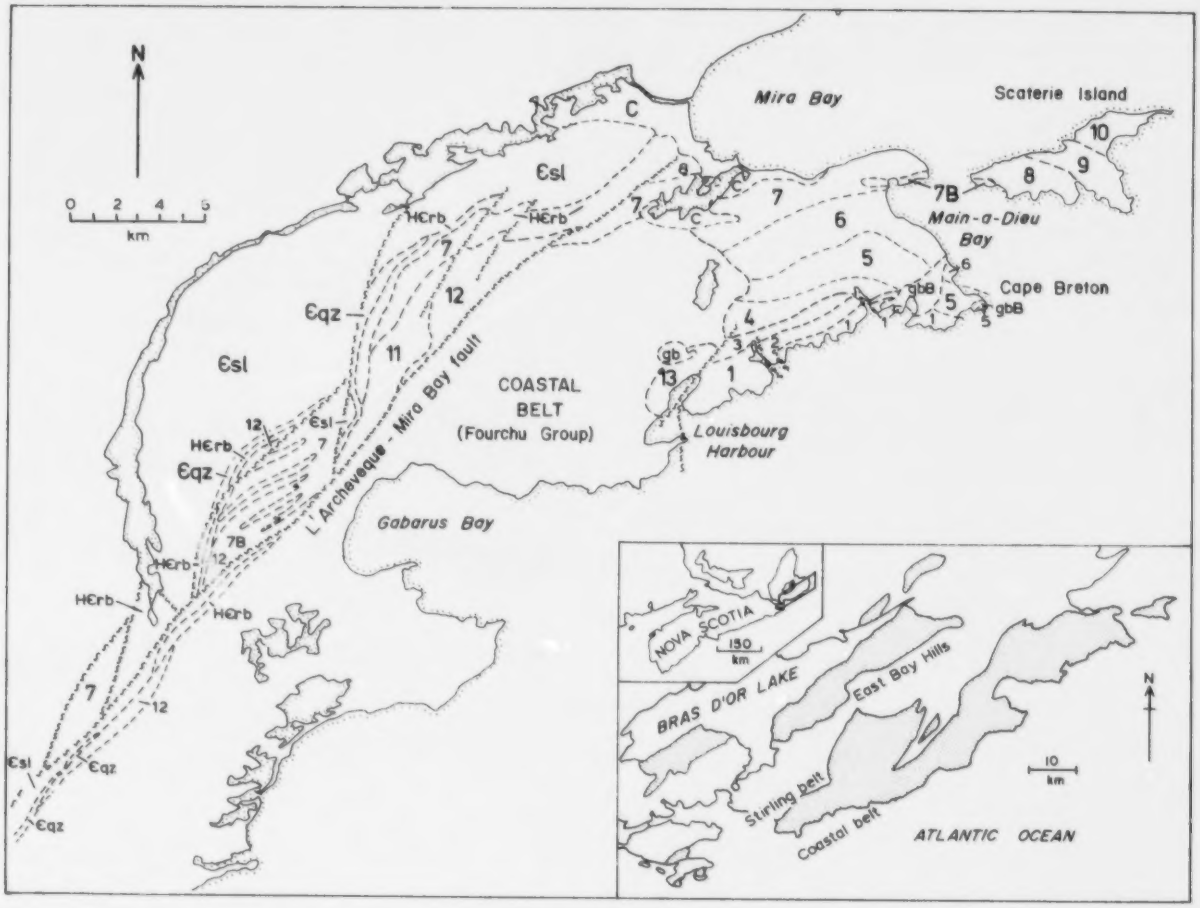

Figure 1. Map showing distribution of units in the Main-a-Dieu sequence and overlying units. Inset map shows distribution of the Fourchu Group and associated plutons (stippled) in southeastern Cape Breton Island.

The Main-a-Dieu sequence may be correlative with lithologically similar parts of the Conception Group in the Avalon terrane of eastern Newfoundland (e.g. O'Brien et al., 1983). The overlying redbed unit could be correlative with the Signal Hill Group, a late Precambrian redbed unit that overlies the Conception Group. The lithologies of the Main-a-Dieu sequence are compatible with formation in basins within a continental margin volcanic arc, perhaps with glacial influence as suggested by Gardiner and Hiscott (1988) for the Conception Group.

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LATE TRIASSIC DINOSAUR FOOTPRINTS AND OTHER TRACE FOSSILS FROM THE WOLFVILLE FORMATION, EASTERN ANNAPOLIS VALLEY, NOVA SCOTIA[1]

B. Cameron[2] and J. R. Jones[2]

INTRODUCTION

The Late Triassic to Early Jurassic rocks of the Fundy Basin in the Annapolis Valley region of Nova Scotia (Figs. 1 and 2) have yielded few fossils (Klein, 1962; Bock, 1969; Thompson, 1974; Jensen, 1975; Cornet, 1977; Olsen et al., 1982). Although our work, begun in the mid-1980s, has confirmed the rarity of fossils in the Wolfville, Blomidon and Scots Bay formations, it has resulted in discovery of some new fossils and fossil localities (Cameron and Jong, 1985; Cameron, 1985, 1986; Cameron et al., 1985; Cameron and Jones, 1987, 1988). Our research involves systematic collecting and measuring of exposures inland and along the coastlines of the Annapolis Valley region, as well as drillcore studies.

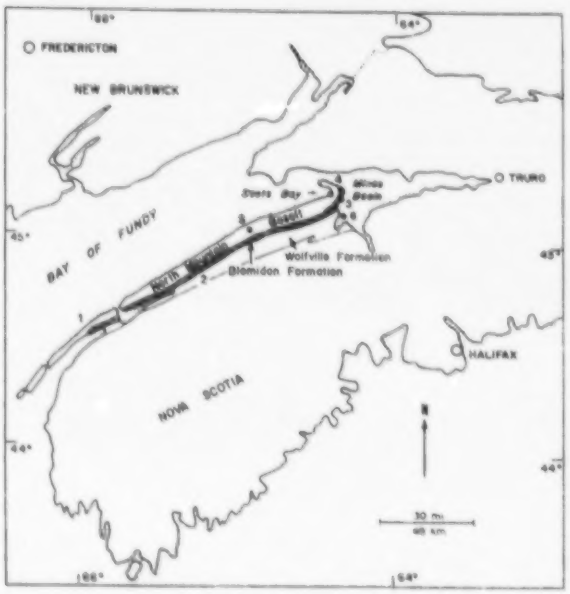


Figure 1. Generalized fossil locality map: (1) Blomidon Formation at St. Mary's Bay; (2) upper Blomidon Formation at Central Clarence; (3) lower Blomidon Formation at Delhaven and Blomidon; (4) Scots Bay Formation in coves southwest of Scots Bay; (5) Getty Mines Ltd. well GAV 77-1 north of North Kingston; (6) middle and upper Wolfville Formation along the southern and western shores of the Minas Basin.

During the fall of 1988 and the summer of 1989, we concentrated on the vertebrate-dominated trace fossil assemblage from the upper Wolfville Formation that was discovered in 1975 (Baird, 1976) near Paddy's Island in North Medford, Kings County. This is a significant fossil assemblage because it may be the oldest known dinosaur footprint locality in Canada. The now famous Parrsboro area dinosaur fossil localities in Nova Scotia are significantly younger, being Early Jurassic in age (Olsen, 1981; Olsen et al., 1982; Olsen and Baird, 1982).

PREVIOUS WORK

The upper Wolfville Formation exposures north of Kingsport (Fig. 1) have yielded root traces (Jensen, 1975) and a cotylosaur skull (Olsen and Baird, 1986) as well as several different kinds of vertebrate footprints and trackways (Baird, 1964). This Late Triassic ichnofaunule has been determined to be of late Carnian or early Norian age by Olsen (1981), Olsen et al. (1982), Baird and Olsen (1983), and Olsen and Baird (1986), who identified possible ornithopod dinosaur tracks (*Atreipus acadianus*), pseudosuchian thecodont tracks (*Brachychirotherium* cf. *B. parvum*), and lizard-like or sphenodontid rhynchocephalian reptile tracks (*Rhynchosauroides* cf. *R. brunswicki*). The paper by Olsen and Baird (1986) represents a most thorough description and analysis of all of the known species of the new trace fossil genus *Atreipus*. However, only the dinosaur footprints *Atreipus acadianus* were illustrated and described from the upper Wolfville Formation of the Paddy Island area. Olsen and Baird (1986) recognized *Tambia*, but did not report it (D. Baird, personal communication, 1989).

UPPER WOLFVILLE ICHNOFAUNULE

Most of the trace fossils in the fluvial deposits of the upper Wolfville Formation occur as convex hyporeliefs (=hypichnia) on the bottoms of medium grained, reddish-brown sandstones. Hyporeliefs or hypichnia are boundary reliefs that occur on the

1 Funding was received from a Natural Sciences and Engineering Research Council general grant to Acadia University
2 Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0

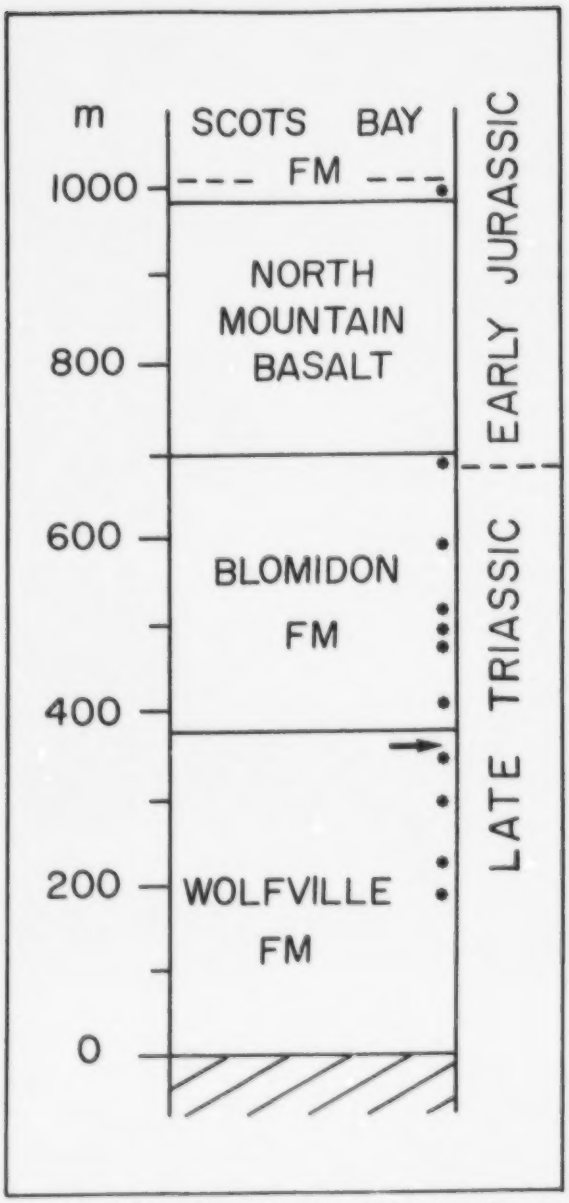


Figure 2. Generalized stratigraphic column for the early Mesozoic rocks of the Annapolis Valley and North Mountain region of Nova Scotia. Asterisks refer, in a generalized manner, to known fossiliferous horizons and intervals. The arrow denotes the approximate level of the dinosaur tracks from the upper Wolfville Formation. (Other dinosaur tracks have been found in the middle Blomidon and the upper Scots Bay formations.)

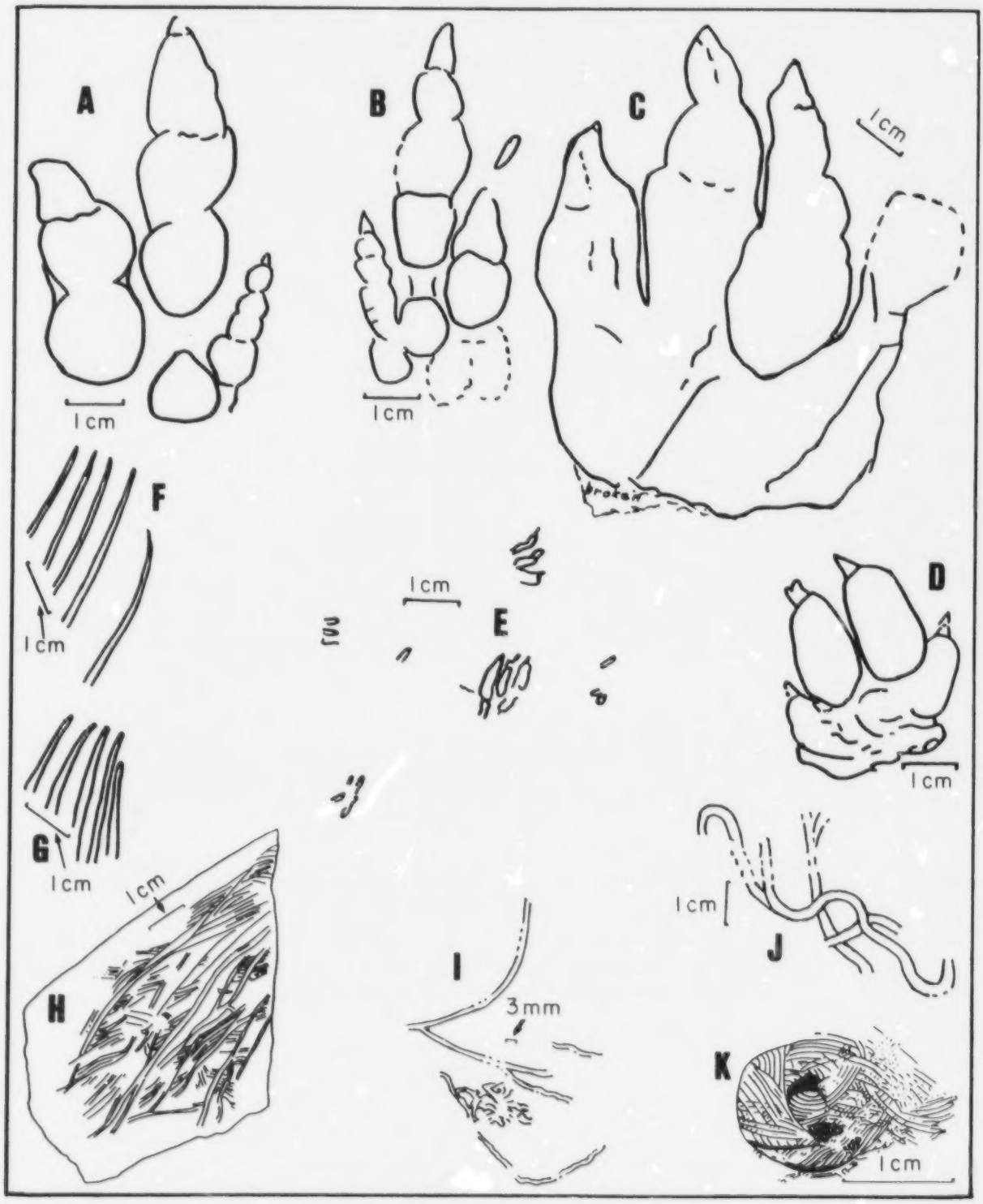
lower surface (=sole or bottom) of a stratum and may be either convex or concave. These sandstones overlay mudcracked red shale layers on and into which the traces were originally made. The vertebrate footprints were molded into the underlying mud at the time of formation and are now preserved as casts on the bottom surfaces of the overlying sandstones.

The footprint assemblage is dominated by the quadrupedal dinosaur tracks *Atreipus acadianus* (Fig. 3A-D). The animal that made these footprints was probably a very early ornithischian dinosaur with a hadrosaur-like manus (= front foot) and a coelurosaur-like pes (= hind foot). Skeletal remains have not yet been found, but it was probably about 0.6 m in height and about 1.7 m in length (Olsen and Baird, 1986). The three-toed (tridactyl) pedes that distinguish it clearly as an early dinosaur are common and well-preserved. The hoof-like, four-toed (tetradactyl) manus prints are less common and not as readily recognized as hind footprints. All other species of *Atreipus* (in the United States and Germany) have a tridactyl manus. No dragging tail marks were observed. No *Grallator*-type dinosaur footprints were recognized.

Associated with these dinosaur footprints are *Rhynchosauroides* cf. *R. brunswicki* (Fig. 3E), which are small footprints of a lizard-like reptile (Baird, 1964), problematical five-toed 'scratch' markings (Fig. 3F-G) of intermediate size that appear to be digging marks, the rillmark-like pseudofossil *Dendrophycus* (Fig. 3H), and at least three kinds of invertebrate traces.

The invertebrate trace fossils include a small *Cochlea*-like twisted trail 2 mm in diameter (Fig. 3J), a less curved and branching unidentified trail 1 mm in diameter (Fig. 3I), and a small new species of *Tambia* (Fig. 3K). *Tambia* is a convex hyporelief mold of a set of somewhat spirally arranged, subparallel, scratch-like markings that formed a donut-like depression on the underlying mud. The apparent digging action may be indicative of a small vertebrate, rather than an invertebrate (P. E. Olsen, personal communication, 1987). *Rhynchosauroides* cf. *R. brunswicki* may have produced the *Tambia* markings while digging in the mud for food.

Figure 3. (facing page) Line drawings of representative vertebrate and invertebrate trace fossils preserved as convex hyporeliefs on the bottoms of sandstone beds from the upper Wolfville Formation near North Medford, Nova Scotia: (A-B) three-toed pedes (hind feet) of Atreipus acadianus (ornithischian dinosaur) with some missing metatarsal-phalangeal pads and an overprinted (dashed lines) partial manus (front foot); (C) poorly preserved, slightly larger dinosaur (?Atreipus) pes (hind foot) that was probably imprinted into softer mud than those above; (D) complete four-toed manus of Atreipus acadianus; (E) footprints of Rhynchosauroides cf. R. brunswicki (lizard-like or sphenodontid rhynchocephalian reptile); (F-G) problematical unnamed five-toed scratch and/or digging marks; (H) Dendrophycus (possibly a pseudofossil resembling rillmarks); (I) unidentified small invertebrate(?) trail [scale bar (see arrow) = 3 mm]; (J) "Cochlea"-like invertebrate(?) trail; (K) streaked spiral structure of Tambia sp. (presumed invertebrate burrow).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Elsewhere within the Wolfville Formation (and the Blomidon Formation), other invertebrate trace fossils are represented by bioturbation, vertical *Skolithos*-like burrows and *Scoyenia* burrows. The invertebrate traces of the Wolfville and Blomidon formations have not yet been well studied. For example, *Cochlea* is an invalid name, *Dendrophycus* may be inorganic, and this is the first time *Tambia* has been reported from North America and from the Triassic Period (Hantzschel, 1975).

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LISCOMB COMPLEX: A GRAVITY STUDY OF THE NORTHERN BOUNDARY

P. J. C. Ryall[1] *and M. Brogan*[2]

INTRODUCTION

Interpretation of gravity data has been used in Nova Scotia to place constraints on the subsurface configuration of granite bodies. For example, Garland (1953), O'Reilly (1975) and Douma (1978) investigated the South Mountain Batholith while MacKenzie (1976) investigated connections between the South Mountain and Musquodoboit Batholiths. More recently, Giles and Chatterjee (1987a) used gravity contours to support the hypothesis of 100 km of sinistral movement on the Tobeatic Fault Zone in southern Nova Scotia.

The Liscomb Complex (formerly known as the Liscomb Pluton) is an irregular bi-lobate granitic body with an area of about 350 km^2. Mapping by Giles and Chatterjee (1987b) of the western half has revealed that it is composite in nature, consisting of a plutonic complex, high grade metamorphic rocks and two diatremes/breccia pipes. Because the existing (Energy, Mines and Resources Canada: EMR) gravity database on the Liscomb Complex area is relatively sparse (typically 2-5 km spacing) we have begun a program of more detailed gravity surveying on the northern boundary of the complex to help delineate its extent.

METHODS

Surveys have been restricted to existing roads, tracks and trails. A LaCoste-Romberg gravity meter (kindly loaned by the Atlantic Geoscience Centre) was used. Elevations relative to existing benchmarks were surveyed using a level and rod or an Omni-1 Total Station 3006 surveying tool (an electronic distance measuring device). Although the error in individual gravity measurements is small ($< \pm 0.05$ mgal) the uncertainty in Bouguer gravity interpretation will be considerably greater because of the variable (3-13 m) thickness of till in the area, as reported by Jennings (1989) who concluded that uncertainties from this source are probably less than 0.5 mgal.

Since the gravity measurements of this survey have not been tied to an absolute reference, they have been adjusted to fit with the existing EMR database. Computer modelling was done using the 2.5D program MAGRAV and the 3D program THREED.

RESULTS

Contoured Bouguer gravity for the area studied is given in Figure 1. Data for this map come from the EMR database, Brogan (1988) and additional survey lines. The major features on this map are: (1) a large low (-10 mgal) in the southeast region associated with the Liscomb Complex, (2) a smaller low (-5 mgal) centred at approximately 45°18'N, 62°47'W due to a small granitoid body (the Liscomb Satellite Pluton of Brogan, 1988) north of the Liscomb Complex and (3) the end of a high band (up to +5 mgal) in the west, probably due to Halifax Formation slates. It is not possible to see this sort of detail using only the much sparser EMR data.

Interpretation by Jennings (1989) suggests that any connection between the Liscomb Satellite Pluton and the Liscomb Complex is deeper than 1 km and that the satellite pluton extends at shallow depth to the northwest of its position indicated on the Geological Map of Nova Scotia (Keppie, 1979).

FUTURE WORK

A few more stations will be measured in the map area of Figure 1 to better define contours in areas where the data density is still low. The major effort, however, will be concentrated south of the Chaplin-Trafalgar road over the Liscomb Complex where it will be necessary to use a boat or canoe on some lakes in order to get suitable areal coverage.

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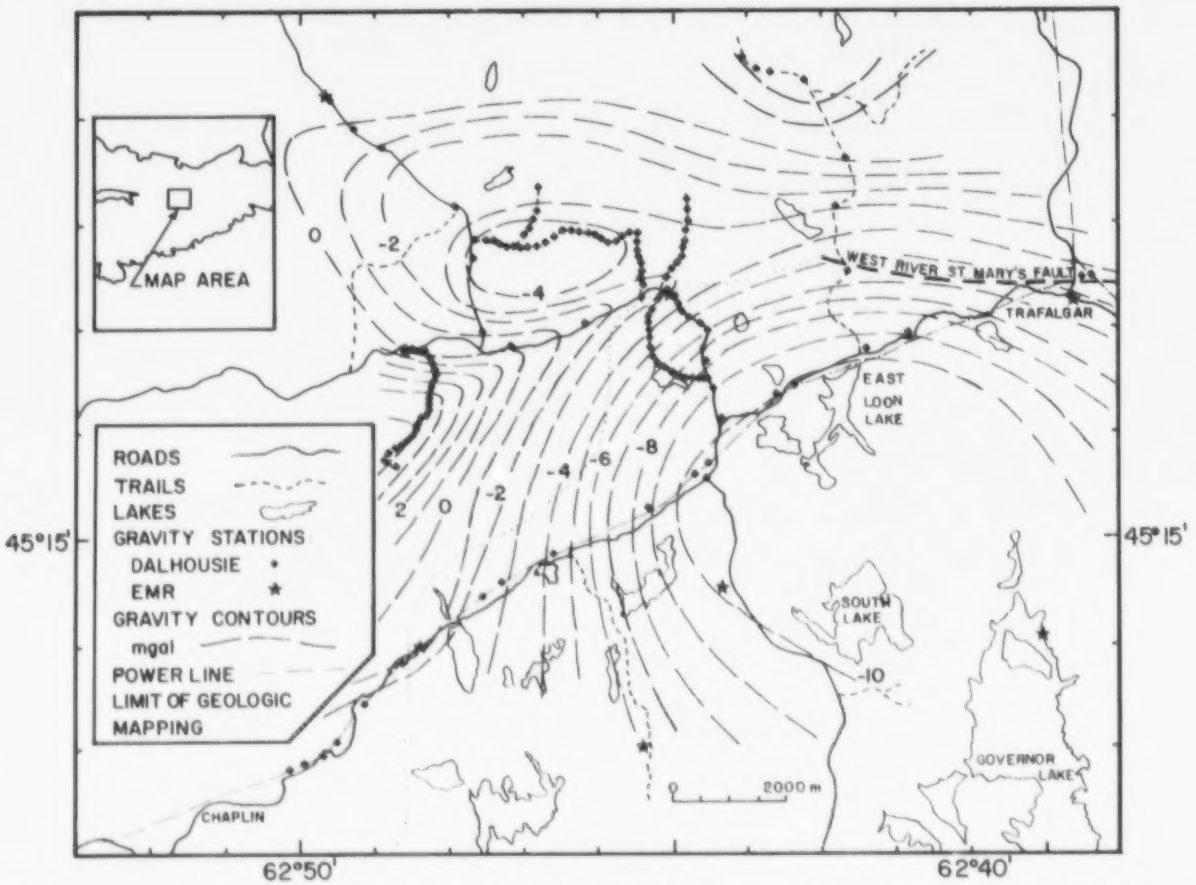

Figure 1. Bouguer gravity contours over the northern boundary of the Liscomb Complex. The complex is located south of the West River St. Mary's Fault and extends to the west at least as far as the limit of geologic mapping (dotted line; Giles and Chatterjee, 1987b).

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AN UNUSUAL VEIN MINERAL ASSEMBLAGE CONTAINING WILLEMITE, CALCITE, TALC AND AMORPHOUS MATERIAL, KIRKMOUNT, NOVA SCOTIA: SIGNIFICANCE FOR MINERAL EXPLORATION[1]

A. L. Sangster[2]

Diamond-drilling at the Kirkmount willemite occurrence has encountered an unusual 28 cm vein, at a depth of 150 m below the present weathering surface, that contains mineralogy and textures distinct from those described previously (Sangster, 1986a, 1986b, 1987). The vein contains the zinc silicate willemite, calcite (4 % - 15 % Mn), talc and a brown amorphous material that forms an integral part of the mineral textures in the vein. The amorphous material contains small crystals of barite. Rhodochrosite occurs with calcite in hairline fractures in the wallrock.

Ragged, coarse-crystalline willemite occurs within quartz cored, radially-crystallized and concentrically banded spherules composed mainly of fine grained calcite and talc. These "rosettes" are overgrown by coarser grained, high-Mn (to 15%) calcite which has well-developed coliform banding. Calcite textures are dominated by spectacular plumose aggregates of calcite needles. The brown amorphous material occurs most conspicuously interlaminated with calcite in a 1 - 2 cm thick band along one margin of the vein. It contains included calcite and very small, feathery barite crystals. Elsewhere, the amorphous material occurs dispersed within the willemite-talc-calcite rosettes and commonly forms a selvage on the surface of the rosettes where they are in contact with calcite. The composition of the amorphous material is given in Table 1.

Table 1. Composition of brown amorphous material, Kirkmount willemite occurrence, from microprobe analyses.

	1	2	3	AVG.
SiO_2	34.77	34.82	34.69	34.76
Fe_2O_3	37.91	37.83	37.71	37.80
Al_2O_3	0.09	0.13	0.00	0.07
CaO	0.82	0.58	0.86	0.75
MgO	2.92	3.38	2.98	3.09
Na_2O	2.44	2.87	2.27	2.53
K_2O	0.08	0.00	0.04	0.04
MnO	3.46	3.60	3.72	3.59
Cr_2O_3	0.11	0.02	0.06	0.06
TiO_2	0.16	0.00	0.10	0.09
TOTAL	82.76	83.23	82.43	82.78

Estimate from probe:

Zn	1 - 2%
S	present

Estimate from hydrogen separation:

H_2O	6.15%
Organic Carbon	present

The Fe- and Si-rich amorphous material resembles colloidal deposits derived by groundwater leaching of soils in areas of arid to semiarid climate (Yariv and Cross, 1979). The coliform banding and plumose crystallization of calcite, the radial crystallization of willemite rosettes and the presence of amorphous material suggests that the observed textures and minerals are a product of rapid crystallization at low temperature from a colloid. On the other hand, the calcite-talc mineral assemblage that occurs with the willemite rosettes may be a relict of the original colloid or may have been the product of a low metamorphic grade reaction between dolomite and quartz.

The recognition of deep vein-filling material, which may have been derived from oxidizing surficial deposits, indicates a period of strong weathering and downward percolating fluids to a deep water table. The vein is interpreted to have formed by supergene processes during the Late

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2 Geological Survey of Canada, 601 Booth Street, Ottawa, Canada K1A 0E8

Paleozoic formation of the Stellarton Graben (Yeo and Ruixing, 1986) when subsidence, probably accompanied by some physical elevation of the Antigonish Highlands, resulted from dextral movement on the Hollow Fault system.

This interpretation has significant implications for mineral exploration in the Antigonish Highlands and possibly in other highland areas of eastern Canada:

(1) Many geochemical anomalies, such as that at Kirkmount, may be a product of weathering of an unusual secondary mineral assemblage not considered to be common in eastern Canada. As a result, the source of the anomaly may be overlooked, thereby passing over deeper, primary mineralization.

(2) The extent of deeper weathering indicated near the Hollow Fault suggests the possibility that sulphide occurrences in areas of high uplift could be deeply weathered, to the point of having no chemical expression of a metallic component other than hematite altering to limonite.

ACKNOWLEDGMENTS

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MARBLE-HOSTED METALLIC MINERAL OCCURRENCES IN CAPE BRETON ISLAND - A GEOLOGICAL SYNOPSIS[1]

J. R. Hill[2]

Geological examination and lithogeochemical sampling of a number of marble-hosted metallic mineral showings and deposits were carried out in 1986 - 1988 during a regional study of pre-Carboniferous metacarbonate rocks in Cape Breton Island. Data were collected from a total of 13 sites containing a variety of metals hosted predominantly in George River Group carbonate rocks underlying the Creignish Hills, North Mountain and Boisdale Hills areas and in minor carbonate members of pre-Carboniferous metasedimentary sequences throughout the Cape Breton Highlands. All host carbonate lithologies have undergone regional metamorphism varying from lowermost greenschist facies to at least middle amphibolite facies.

Two major metallogenic categories of marble-hosted mineralization were recognized on the basis of metal association, gangue mineralogy, form and distribution of mineralization, and lithologic association. The largest group of showings display the characteristics of polymetallic skarn deposits. Mineralization is both carbonate and intrusive-hosted and is related to a discrete contact metamorphic and metasomatic event. A distinct gangue mineral assemblage representing a grade of metamorphism higher than the regional grade is present. Occurrences of this type are further subdivided according to metal association into: (a) Fe $\pm$ Cu skarn, (b) Fe + Cu $\pm$ W, Mo, Sn skarn, and (c) Pb + Zn + Ag $\pm$ Au, Cu skarn. Iron skarns, such as those found in the Glencoe area of the Creignish Hills and at Scotch Lake in the northern Boisdale Hills, are dominated by magnetite with minor pyrite and trace sphalerite or chalcopyrite. Fe-Cu skarns are represented by showings in the Glencoe area, near Whycocomagh, in the Leitches Creek area of the Boisdale Hills and near McMillans Brook in the central Cape Breton Highlands. Pyrite and chalcopyrite are the principal metallic minerals while accessory Sn-,Mo- and W-bearing minerals may be present. Host lithologies are mixed calcite and dolomite marbles in contact with felsic granitoid intrusives. Pb-Zn-Ag skarn mineralization is found at Rear Boisdale in the southern Boisdale Hills hosted in graphitic calcite marble. Galena, sphalerite, pyrite and accessory chalcopyrite are associated with anomalous Au and Ag in massive, disseminated and stringer sulphide zones.

The second category of mineralization includes stratabound deposits of iron or base metals. Mineralization is neither related to a definite contact metamorphic event nor is it associated with calc-silicate-bearing marble lithologies of higher metamorphic grade than the regional grade. Occurrences of this type can be further subdivided according to morphology and metal association into: (a) stratiform Zn or Fe mineralization and (b) irregular disseminated Cu-Pb-Zn. Significant stratiform Zn deposits occur at Lime Hill in southwestern Cape Breton Island and at Meat Cove in the northernmost Cape Breton Highlands. Both deposits are characterized by the dominance of banded disseminated sphalerite hosted within siliceous

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2 Northwood Geoscience, 32 Nolan Street, Ottawa, Ontario K1Y 3R3

dolomite marble of medium to high regional metamorphic grade. In contrast, disseminated Cu-Pb-Zn sulphide mineralization hosted in regionally metamorphosed marbles of the George River Group is characterized by <5% combined galena, sphalerite, chalcopyrite and pyrite hosted in relatively pure calcite and dolomite marble lithologies.

Two general models for base/precious metal exploration within marbles of Cape Breton Island are suggested: (1) polymetallic skarn deposit types as observed at Whycocomagh Mountain (Fe-Cu-W-Mo), Rear Boisdale (Zn-Pb-Ag-Au) and McMillans Brook (Fe-Cu-Sn-Mo-W) which are largely restricted to calcite marbles and (2) stratiform Zn deposits such as those found at Lime Hill and Meat Cove which are found only in high metamorphic grade siliceous dolomite marbles.

Regional lithogeochemical anomalies in the Boisdale Hills marbles may indicate a higher than average potential in that area.

THE GEOLOGY OF THE JUBILEE ZINC-LEAD DEPOSIT, VICTORIA COUNTY, CAPE BRETON ISLAND, NOVA SCOTIA[1]

M. C. Graves[2], F. J. Hein[3] and A. Ruffman[4]

The purpose of this report is twofold. Firstly, it recounts the early exploration history of the Jubilee deposit in the area of the discovery outcrop and the Green Pond adit. A compilation map of pre-1948 exploration activity allows assessment of this work. Secondly, a sedimentary facies analyses using core from the potential ore zone drilled in 1977 confirms previous conclusions that growth faulting was important in the sedimentation history of the host rocks. Facies isopach maps and metal maps (m%Zn, m%Pb and m%Zn+Pb) allow the relation between mineralization and carbonate facies to be assessed.

Analysis of maps, correspondence and documents of the early exploration history of the Jubilee deposit shows that significant exploration began in 1933-34 by the driving of at least three exploration adits. The Green Pond adit was the longest and best documented. It was 40 m long and tested only the overburden/subcrop surface near the discovery outcrop. Results were encouraging but were not confirmed by later drilling into bedrock in the immediate vicinity in 1937 and 1948.

Stratabound zinc and lead mineralization occur at Jubilee in Carboniferous limestone, particularly where it is brecciated. The footwall of the Jubilee deposit consists of conglomerate (Horton Group) overlain by laminated limestone (Macumber lithology, Windsor Group). The hanging wall is massive anhydrite (Windsor Group). The limestone breccia is better developed and thicker in a narrow band parallel to the Jubilee Fault. Laterally this brecciated limestone passes into the interlaminated anhydrite-limestone unit. The breccia appears to have formed by solution of anhydrite from this interbedded zone, which resulted in an accumulation of undissolved limestone fragments.

Anomalously thick laminated limestones occur beneath the limestone breccia. The breccia unit reaches a maximum thickness of 15 m and is usually thicker than the transitional zone (3-7 m in areas removed from faults) from which it was thought to be derived. These features cannot be explained solely on the basis of a secondary origin for the breccia but suggest that the Jubilee Fault (and possibly others) were growth faults which affected sedimentation in the area.

1 Contribution to the Canada - Nova Scotia Mineral Development Agreement 1984-89. Project carried by Geological Survey of Canada, Economic Geology and Mineralogy Division. Abstract submitted with report to be released as Geological Survey of Canada, Open File Report, March 31, 1989

2 Cuesta Research Limited, 154 Victoria Road, Dartmouth, Nova Scotia

3 Department of Geology, Dalhousie University, Halifax, Nova Scotia

4 Geomarine Associates Limited, P.O. Box 41, Station M, 5112 Prince Street, Halifax, Nova Scotia

AEROMAGNETIC/GRADIOMETER/VLF-EM SURVEYS, CANADA - NOVA SCOTIA MINERAL DEVELOPMENT AGREEMENT[1]

J. Tod[2], E. Ready and P. Stone

The existing aeromagnetic total field coverage of Nova Scotia was compiled as part of the National Earth Science 1:1 000 000 map series, on a 813 m grid. The data set includes federal-provincial and private regional surveys.

Between 1976 and 1983, the Geological Survey of Canada experimental surveys group carried out five experimental surveys to demonstrate the effectiveness of vertical gradiometry as a detail mapping tool. As a result, additional areas were either flown or purchased under the Canada - Nova Scotia Mineral Development Agreement (1984 - 1989). The lithological and structural information that can be gained from this higher sensitivity data is significantly greater than available from the older data set.

The results are available as digital profile and gridded data, as well as map products. Gradiometer and total field contour maps are available at 1:25 000 scale, total field and gradiometer colour interval maps with VLF-EM profiles plotted on the reverse, at 1:50 000 scale.

1 Funded by Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement

2 Energy, Mines and Resources Canada, 1 Observatory Crescent, Ottawa, Canada K1A 0Y3

AIRBORNE GAMMA RAY SPECTROMETRY[1], AND BEDROCK[2] AND SURFICIAL[2] GEOLOGY OF THE DAVIS LAKE PLUTON

K. L. Ford[3], M. A. MacDonald, P. W. Finck, F. J. Boner, L. J. Ham, R. J. Horne, M. C. Corey and R. M. Graves

In the fall of 1987, the Geological Survey of Canada conducted a multi-parameter (gamma ray spectrometric, total field magnetic and VLF-EM) airborne geophysical survey of the Davis Lake Pluton (DLP), the southwestern portion of the South Mountain Batholith in southwestern Nova Scotia (Fig. 1) as a contribution to the Canada - Nova Scotia Mineral Development Agreement, 1984-1989. In studies of other areas within the Meguma Terrane (Fig. 1) of Nova Scotia (e.g. Ford and O'Reilly, 1985; Corey, 1987) it has been shown that interpretation of the airborne gamma ray spectrometric signature for a particular granitic unit or area must consider several factors. These factors include not only the cumulative effects of magmatic differentiation and varying intensities of late- and/or post-magmatic alteration but also the effects of variations in the provenance and thickness of the overlying Pleistocene deposits. This latter factor is particularly important for the DLP where a paucity of outcrop has left many prominent radioelement features unexplained with respect to their bedrock source.

However, the airborne geophysical results over the DLP provide information that can be directly interpreted in terms of surface geology. Where ground control is provided by detailed surficial mapping of till clast matrix composition, there are often excellent correlations between (1) areas of Meguma Group derived tills with anomalously low radioelement signatures and also between (2) areas of granite derived tills with anomalously high radioelement signatures. Such areas include the northwest contact of the DLP where sharp increases in several radioelement parameters (e.g. equivalent uranium, equivalent potassium, equivalent uranium/equivalent thorium) correspond

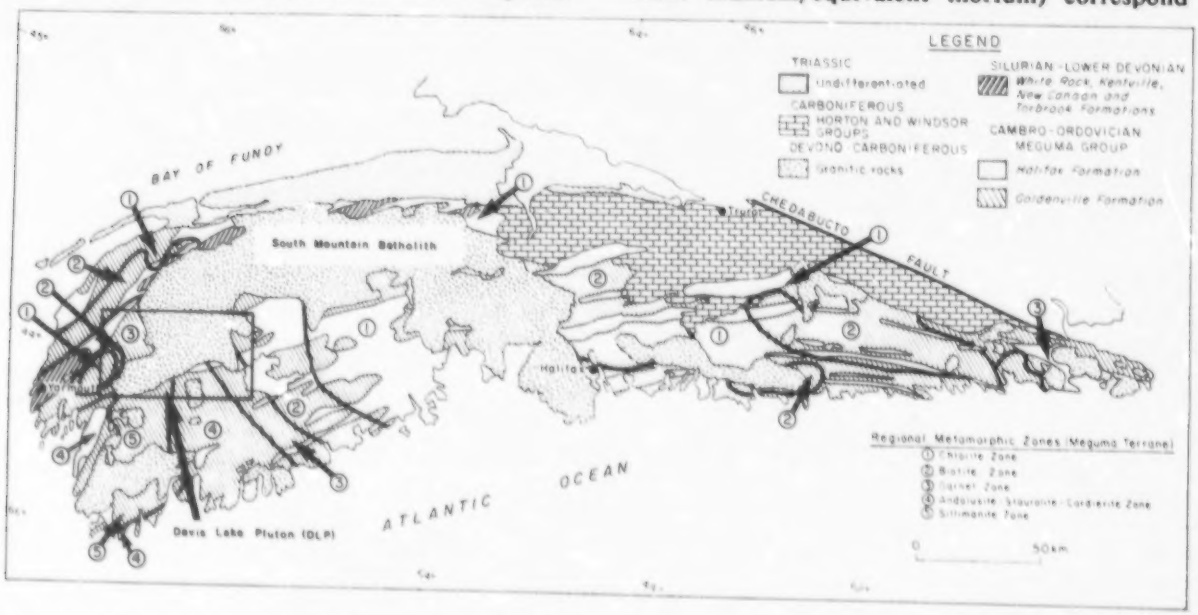

Figure 1. Geology of the Meguma Terrane showing the location of the South Mountain Batholith (SMB) and the Davis Lake Pluton (DLP).

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2 Funded by the Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement
3 Mineral Resources Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8

directly with an abrupt change in till clast nature from Meguma Group derived tills to granite derived till. These abrupt changes additionally agree well with the position of the Meguma Group-granite contact as defined by diamond-drilling by Shell Canada Resources and Rio Algom Ltd. in the East Kemptville tin mine area.

These characteristics of the northwest contact contrast with the nature of the southeast contact of the DLP. In the area of the southeast contact, the contact is poorly defined by diffuse radioelement patterns and this diffuse nature corresponds closely with an observed dispersion of granite derived till >5 km southeastward over Meguma Group bedrock. In this case, the diminishing radioelement values away from the contact reflect: (1) the diminishing down-ice dispersion of granite derived clasts in the till and (2) to a greater degree, the decreasing content of granite derived material in the till matrix. On a more local scale, the most western portion of the DLP displays anomalously low radioelement patterns. This pattern corresponds to an area of Meguma Group derived till which has been transported approximately 3 km southward across the granite. The above examples suggest a complicated local Pleistocene history with till in some areas displaying little glacial dispersion while in adjacent areas showing large scale dispersion. Details of these patterns can be seen on posters of the display.

The lack of bedrock outcrop has left several prominent radioelement features unexplained in terms of a bedrock source. One such feature is a horseshoe shaped equivalent uranium/equivalent thorium (eU/eTh) anomaly in the central part of the survey area. The western part of the anomaly is underlain by the eastern half of a unit termed the Dog Lake leucomonzogranite porphyry. However, the eastern and southern parts of the anomaly are considered to be underlain by another unit, the Davis Lake leucomonzogranite, although the outcrop and drillhole information is extremely limited. These high eU/eTh values may represent a late- and/or post-magmatic alteration of the Davis Lake leucomonzogranite similar to alteration noted elsewhere in the Meguma Terrane (Ford and O'Reilly, 1985; Corey, 1987; O'Reilly et al., 1988) or may suggest that there are some unexposed porphyry bodies in these areas. The presence of porphyry is suggested by increased amounts of porphyry clasts in the tills, with the areas of increased amounts crudely corresponding to the radiometrically anomalous areas. Although the percentage of porphyry in the clast fraction of the till is generally <15%, the amount of till matrix derived from granite may be much higher given the amount of glacial dispersion observed in this area (>5 km).

Another example of unexplained radioelement features is in the area around the East Kemptville tin deposit (see MacDonald et al., 1989, for location) where there is a prominent eU/eTh ratio anomaly which does not correspond to lithological boundaries based on outcrop and drill core information. This anomaly may represent an alteration signature associated with the East Kemptville deposit or may be the result of dispersal of glacial material from around the deposit or both. As noted previously, there is an abrupt change in till types along the northern edge of the DLP and that characteristic suggests local derivation of the tills. It has also been noted by the results of the till clast survey that there are virtually no East Kemptville leucogranite (the unit hosting the tin mine; Kontak, 1987) clasts in the tills south of the deposit. Preliminary till geochemistry supports previous industry work that documented a large scale, southeasterly-dispersed Sn anomaly. The nature of this anomaly suggests that, at least in this area, till matrix and till clasts: (1) reflect varying degrees of dispersion and (2) have a distinct and different provenance. North of the East Kemptville deposit, a large area of anomalously low eU/eTh ratio values corresponds to a biotite-rich (6-8% biotite), predominantly whitish-grey phase of the Davis Lake leucomonzogranite whereas to the east, the higher eU/eTh ratio area corresponds with a more biotite-poor (4-6% biotite), bluish-grey phase of the Davis Lake leucomonzogranite. It is unclear if this predominant bluish-grey colour, which is associated with alkali-feldspar megacrysts, reflects a primary feature or is the result of some large scale, pervasive alteration.

In contrast to the majority of other peraluminous granites of the Meguma Terrane (e.g. Ford and O'Reilly, 1985), the portion of the Davis Lake leucomonzogranite southeast of the East Kemptville deposit displays some of the highest equivalent thorium values of any granitoid in the Meguma Terrane. Limited bedrock control, however, does not provide an obvious explanation for these values within the Davis Lake leucomonzogranite southwest and east of the deposit. Recent bedrock and surficial geological mapping of the DLP by the Nova Scotia Department of Mines and Energy has provided plausible explanations for many of the radioelement patterns mapped by a recent airborne geophysical survey. These results, when combined with studies from other areas of the Meguma Terrane, demonstrate that airborne gamma ray spectrometry can be a valuable aid to regional and

detailed bedrock and surficial geological mapping and mineral exploration. Clearly, in areas where different bedrock units have sufficient radioelement contrasts, the airborne geophysical surveys are an excellent predictive tool for mapping not only the Pleistocene deposits but also for mapping the bedrock geology through variations in magmatic differentiation and the superimposed effects of late- and/or post-magmatic metasomatism and hydrothermal alteration. This last feature has important applications to mineral exploration because of the common association of granophile-element mineral deposits with these areas of pervasive alteration.

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PALEOMAGNETISM OF CARBONIFEROUS STRATA IN STELLARTON GRABEN, NOVA SCOTIA: SIGNIFICANCE TO LOCAL TECTONISM AND SEDIMENTATION[1]

G. M. Yeo[2] and W. A. Morris[3]

Investigation of the paleomagnetism of redbeds in Stellarton Graben was undertaken to attempt to constrain the timing of deposition of critical redbed units and to assess the amount of angular rotation involved in development of the pull-apart graben.

Four sets of magnetic remanences were distinguished (Table 1). ST_1 was found only in the Namurian Canso Group (Fig. 1). As it was not found in younger rocks it probably represents a late Namurian to Westphalian B diagenetic event. The other three sets of remanences, ST_{2-4}, overlap sufficiently that they were grouped for preliminary interpretation (Fig. 1). A negative fold test on the ST_2 data suggests that it postdates deformation of the Stellarton Formation, and is thus post-Westphalian D. The times of acquisition of the ST_3 and ST_4 remanences are also poorly constrained. The absence of such remanences from Canso redbeds indicates a post-Namurian age. Their mean positions intermediate between the ST_1 and ST_2 poles suggest that they may have been acquired during graben formation or after filling (Westphalian C - D).

Table 1. Mean paleomagnetic remanence values for middle to late Carboniferous strata in Stellarton Graben (Ca = Canso Group, Cu = Cumberland Group, St = Stellarton Group).

Remanence	Azimuth	Incl.	No.	Strat. Unit
ST_1	082°	+ 4	6	Ca
ST_2	168°	+27	13	Ca, Cu, St
ST_3	178°	+ 8	11	Cu, St
ST_4	171°	- 8	9	Cu, St
ST_{2-4}	173°	+12		

The divergence between ST_1 and ST_{2-4} results from either progressive anti-clockwise rotation of the pole to Stellarton Graben through 65 - 80° or clockwise rotation through 100 - 115°. The smaller rotation is more likely. Apparent anti-clockwise shifting of the magnetic vectors with respect to Stellarton Graben would result from clockwise rotation of the graben and/or clockwise rotation of a much larger area. Roy and Morris (1983) interpreted the eastern Canadian Carboniferous basin to have undergone about 16° of clockwise rotation during the Pennsylvanian. Since this is not nearly enough to accommodate the observed rotation, the graben area must have undergone considerable rotation. Such clockwise rotation is consistent with evidence for late Carboniferous dextral strike-slip on the eastern Cobequid and Hollow faults which bound it (Yeo and Gao, 1987). Most of this displacement must have occurred before or during deposition of the Cumberland Group (Westphalian B to C). Assuming a maximum width of 6 km for the graben, simple calculations suggest that maximum total displacement on the bounding faults was 6.5 to 17 km.

Graben rotation took the form of progressive brittle, simple shearing of a parallelogram-shaped area in the dextral offset between the bounding faults. Pervasive development of Riedel fractures, ranging from microcracks to macro-faults, should have resulted throughout the area of strain. The net effect of such dilatancy would have been doming of the area. This may account for the shedding of the New Glasgow conglomerate northward from the graben area during or immediately following this deformation event.

Graben subsidence post-dates the main episode of strike-slip on the bounding faults. The spread of ST_{2-4} data may reflect a minor amount of apparent anti-clockwise pole shift due to continued dextral strike-slip.

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2 Geology Department, Acadia University, Wolfville, Nova Scotia B0P 1X0
3 Magnetics Inc., RR 2, Lucan, Ontario N0M 2J0

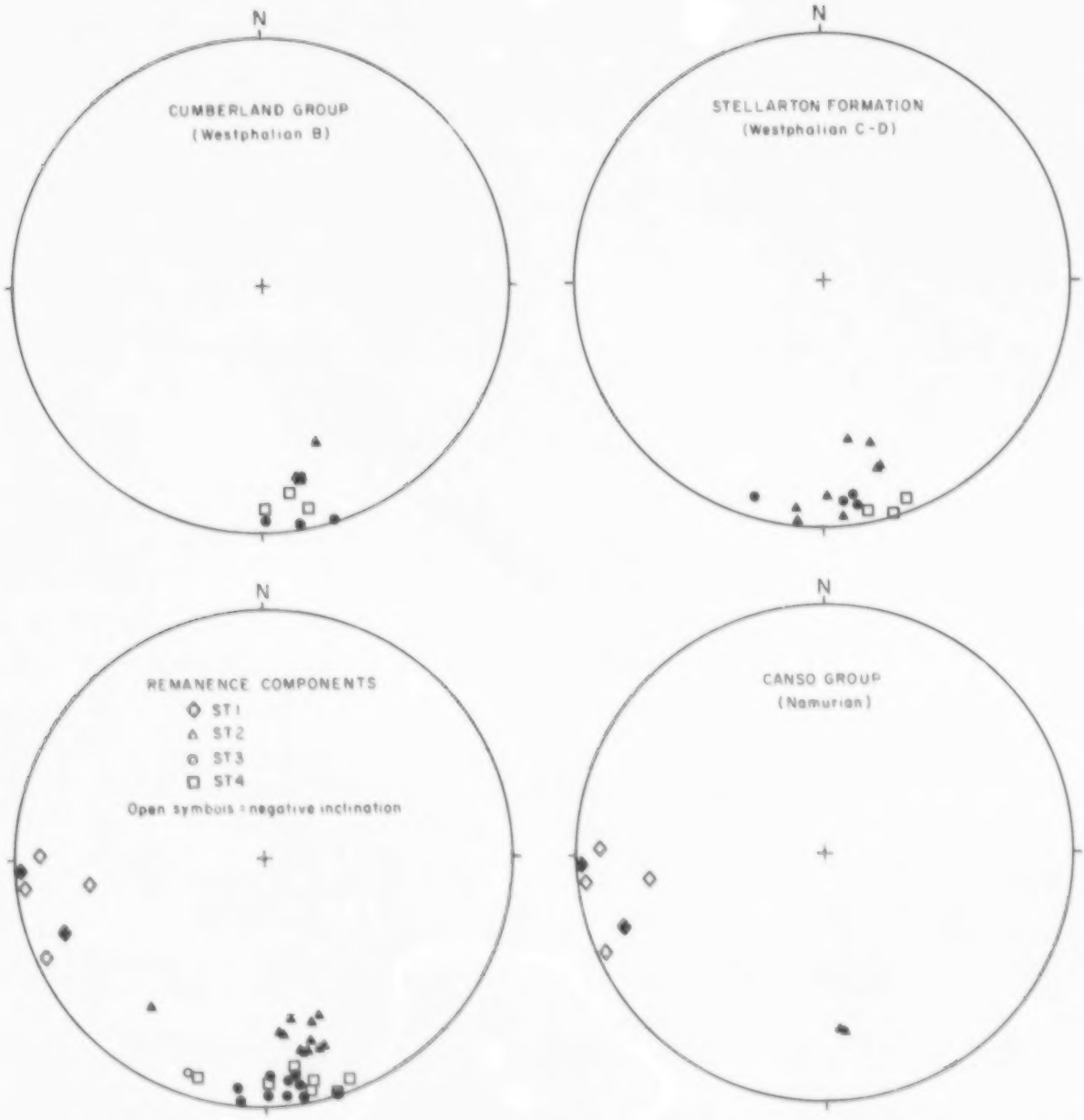


Figure 1. Magnetic remanence vectors from Carboniferous redbeds in Stellarton Graben plotted as poles on lower hemisphere plots. Canso Group data are from the East River and Middle River, Cumberland Group data are from the Middle River and Skinner Brook, and Stellarton Formation data are from various sites within the Stellarton Graben.

REFERENCES

Roy, J. L. and Morris, W. A. 1983: A review of paleomagnetic results from the Carboniferous of North America; the concept of Carboniferous geomagnetic field horizon markers; Earth and Planetary Science, v. 65, p. 167-181.

Yeo, G. M. and Gao, R. 1987: Stellarton Graben: an upper Carboniferous pull-apart graben in northern Nova Scotia; *in* Sedimentary Basins and Basin-forming Mechanisms, eds. C. Beaumont and A. J. Tankard; Canadian Society of Petroleum Geologists, Memoir 12, p. 299-309.

65°00'

BAY OF FUNDY

Kingston

Middleton

Bridgetown

201

1

10

T

SD

€O

bmg

bgd

64°00'

SD

€O

C

bgd

bmg

gn

201

12

101

102

103

10

DARTMOUTH

HALIFAX

St. Margarets Bay

Mahone Bay

€O
bmd
bmg
bmg
bgd
bmg
bmg
bmg
SD
bmg
bgd
SD
bgd
€O
€O
€O
Kejimkujik Lake
Lake
Rossignol
bmg
bmg
bgd
€O
€O
bmg
10
8
103
Liverpool
44°00
65°00'

bmg

bmg

bmg

bmg

bmg

bmg

€O

Mahone Bay

10

Bridgewater

Lunenburg

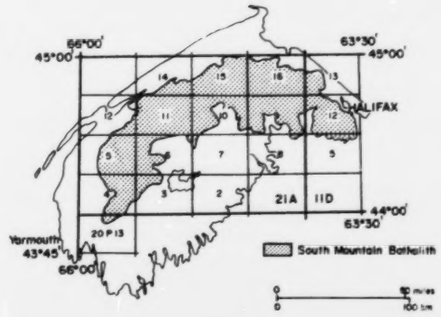
8

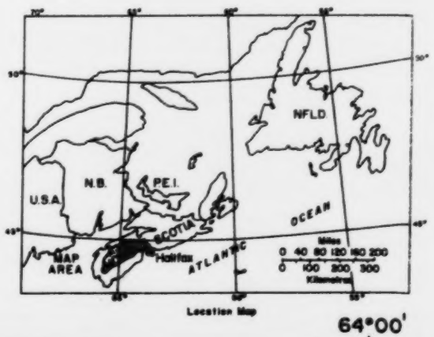
103

Liverpool

5 0 5 10 15 km

SCALE 1:250000





64°00'

LEGEND

TRIASSIC

T — Undivided metavolcanic and metasedimentary rocks

CARBONIFEROUS

C — Undivided sedimentary rocks

DEVONO-CARBONIFEROUS

(0.7%) Leucogranite (LUGR): f- to m-grained; equi, porp, apli, pegm, seri; 0-2% bi, 2-25% mu, tr - 2% co, 0-2% tz, 0-2 ad; no xenoliths.

(6.2%) Fine grained leucomonzogranite (FGLMG): f- to m-grained; equi, porp, apli, pegm, seri; 2-7% bi, 1-5% mu, 0-5% KN, 0-tr gr, 0-2% ad; no xenoliths.

(24.8%) Coarse grained leucomonzogranite (CGLMG): m- to c-grained; mega, seri (minor equi); 3-7% bi, 1-5% mu, tr-4% co, 0-4% KN, 0-tr gr, 0-tr ad; rare xenoliths.

(0.7%) Intrusive suite (INT): f- to c-grained; equi, seri, apli; pegm, mega; 2-10% bi, tr-4% mu, tr-2% co, tr-4% gr, 0-2% KN, no xenoliths.

(9.2%) Muscovite-biotite monzogranite (MBMG): f- to c-grained; mega; seri (minor porp); 4-13% bi, tr-2% mu, 0-2% co, 0-tr gr, 0-40% KN; rare to common xenoliths.

bmg (40.6%) Biotite monzongranite (BMG): f- to c-grained; mega, seri (minor porp); 8-18% bi, 0-tr mu, 0-tr co, (locally 3%), 0-19% gr, 0-30% KN; common to abundant xenoliths.

bgd (17.8%) Biotite granodiorite (BGD): f- to c-grained; mega, seri (minor equi, porp); 12-30% bi, 0-tr mu, 0-tr co, 0-tr gr, 0-15% KN; common to abundant xenoliths.

mp (trace) Mafic porphyry (MP): f- to m-grained; porp; 10-20% bi, 0-tr mu, 0-tr gr; common to abundant xenoliths.

SILURO-DEVONIAN

SD — Undivided metasedimentary and minor metavolcanic rocks and rare mafic intrusions.

CAMBRO-ORDOVICIAN

€O — Undivided metasedimentary rocks.

UNKNOWN AGE

gn — Gneissic rocks.

SYMBOLS

Geological boundary .....

Fault .....

Shear zone (after Smith, 1985 and O'Reilly, 1988) ....

Abbreviations: f - fine, m - medium, c - coarse, equi - equigranular, porp - porphyritic, apli - aplitic, pegm - pegmatitic, seri - seriate, mega - megacrystic, bi - biotite, mu - muscovite, gr - garnet, co - cordierite, KN -alkali feldspar megacrysts, tr - trace, tz-topaz, ad - andalusite.

44°00'